

The Addison-Wesley Signature Series

*"Any fool can write code that a computer can understand.
Good programmers write code that humans can understand."*

—M. Fowler (1999)



REFACTORING

Improving the Design of Existing Code

Martin Fowler

with contributions by
Kent Beck



SECOND EDITION



List of Refactorings

Change Function Declaration (124)
Change Reference to Value (252)
Change Value to Reference (256)
Collapse Hierarchy (380)
Combine Functions into Class (144)
Combine Functions into Transform (149)
Consolidate Conditional Expression (263)
Decompose Conditional (260)
Encapsulate Collection (170)
Encapsulate Record (162)
Encapsulate Variable (132)
Extract Class (182)
Extract Function (106)
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Extract Variable (119)
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Inline Class (186)
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Introduce Assertion (302)
Introduce Parameter Object (140)
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Replace Temp with Query (178)
Replace Type Code with Subclasses (362)
Separate Query from Modifier (306)
Slide Statements (223)
Split Loop (227)
Split Phase (154)
Split Variable (240)
Substitute Algorithm (195)



Refactoring

Second Edition

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with contributions by Kent Beck

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For Cindy

—Martin

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Foreword to the First Edition

“Refactoring” was conceived in Smalltalk circles, but it wasn’t long before it found its way into other programming language camps. Because refactoring is integral to framework development, the term comes up quickly when “frameworkers” talk about their craft. It comes up when they refine their class hierarchies and when they rave about how many lines of code they were able to delete. Frameworkers know that a framework won’t be right the first time around—it must evolve as they gain experience. They also know that the code will be read and modified more frequently than it will be written. The key to keeping code readable and modifiable is refactoring—for frameworks, in particular, but also for software in general.

So, what’s the problem? Simply this: Refactoring is risky. It requires changes to working code that can introduce subtle bugs. Refactoring, if not done properly, can set you back days, even weeks. And refactoring becomes riskier when practiced informally or ad hoc. You start digging in the code. Soon you discover new opportunities for change, and you dig deeper. The more you dig, the more stuff you turn up. . . and the more changes you make. Eventually you dig yourself into a hole you can’t get out of. To avoid digging your own grave, refactoring must be done systematically. When my coauthors and I wrote *Design Patterns*, we mentioned that design patterns provide targets for refactorings. However, identifying the target is only one part of the problem; transforming your code so that you get there is another challenge.

Martin Fowler and the contributing authors make an invaluable contribution to object-oriented software development by shedding light on the refactoring process. This book explains the principles and best practices of refactoring, and points out when and where you should start digging in your code to improve it. At the book’s core is a comprehensive catalog of refactorings. Each refactoring describes the motivation and mechanics of a proven code transformation. Some of the refactorings, such as Extract Method or Move Field, may seem obvious.

But don’t be fooled. Understanding the mechanics of such refactorings is the key to refactoring in a disciplined way. The refactorings in this book will help you change your code one small step at a time, thus reducing the risks of evolving

your design. You will quickly add these refactorings and their names to your development vocabulary.

My first experience with disciplined, “one step at a time” refactoring was when I was pair-programming at 30,000 feet with Kent Beck. He made sure that we applied refactorings from this book’s catalog one step at a time. I was amazed at how well this practice worked. Not only did my confidence in the resulting code increase, I also felt less stressed. I highly recommend you try these refactorings: You and your code will feel much better for it.

— *Erich Gamma, Object Technology International, Inc.*
January 1999

Preface

Once upon a time, a consultant made a visit to a development project in order to look at some of the code that had been written. As he wandered through the class hierarchy at the center of the system, the consultant found it rather messy. The higher-level classes made certain assumptions about how the classes would work—assumptions that were embodied in inherited code. That code didn't suit all the subclasses, however, and was overridden quite heavily. Slight modifications to the superclass would have greatly reduced the need to override it. In other places, an intention of the superclass had not been properly understood, and behavior present in the superclass was duplicated. In yet other places, several subclasses did the same thing with code that could clearly be moved up the hierarchy.

The consultant recommended to the project management that the code be looked at and cleaned up—but the project management wasn't enthusiastic. The code seemed to work and there were considerable schedule pressures. The managers said they would get around to it at some later point.

The consultant had also shown what was going on to the programmers working on the hierarchy. The programmers were keen and saw the problem. They knew that it wasn't really their fault; sometimes, a new pair of eyes is needed to spot the problem. So the programmers spent a day or two cleaning up the hierarchy. When finished, they had removed half the code in the hierarchy without reducing its functionality. They were pleased with the result and found that it became quicker and easier both to add new classes and to use the classes in the rest of the system.

The project management was not pleased. Schedules were tight and there was a lot of work to do. These two programmers had spent two days doing work that added nothing to the many features the system had to deliver in a few months' time. The old code had worked just fine. Yes, the design was a bit more "pure" and a bit more "clean." But the project had to ship code that worked, not code that would please an academic. The consultant suggested that a similar cleanup should be done on other central parts of the system, which might halt the project

for a week or two. All this was to make the code look better, not to make it do anything it didn't already do.

How do you feel about this story? Do you think the consultant was right to suggest further cleanup? Or do you follow that old engineering adage, "if it works, don't fix it"?

I must admit to some bias here. I was that consultant. Six months later, the project failed, in large part because the code was too complex to debug or tune to acceptable performance.

The consultant Kent Beck was brought in to restart the project—an exercise that involved rewriting almost the whole system from scratch. He did several things differently, but one of the most important changes was to insist on continuous cleaning up of the code using refactoring. The improved effectiveness of the team, and the role refactoring played, is what inspired me to write the first edition of this book—so I could pass on the knowledge that Kent and others have acquired by using refactoring to improve the quality of software.

Since then, refactoring has become an accepted part of the vocabulary of programming. And the original book has stood up rather well. However, eighteen years is an old age for a programming book, so I felt it was time to go back and rework it. Doing this had me rewrite pretty much every page in the book. But, in a sense, very little has changed. The essence of refactoring is the same; most of the key refactorings remain essentially the same. But I do hope that the rewriting will help more people learn how to do refactoring effectively.

What Is Refactoring?

Refactoring is the process of changing a software system in a way that does not alter the external behavior of the code yet improves its internal structure. It is a disciplined way to clean up code that minimizes the chances of introducing bugs. In essence, when you refactor, you are improving the design of the code after it has been written.

"Improving the design after it has been written." That's an odd turn of phrase. For much of the history of software development, most people believed that we design first, and only when done with design should we code. Over time, the code will be modified, and the integrity of the system—its structure according to that design—gradually fades. The code slowly sinks from engineering to hacking.

Refactoring is the opposite of this practice. With refactoring, we can take a bad, even chaotic, design and rework it into well-structured code. Each step is simple—even simplistic. I move a field from one class to another, pull some code out of a method to make it into its own method, or push some code up or down a hierarchy. Yet the cumulative effect of these small changes can radically improve the design. It is the exact reverse of the notion of software decay.

With refactoring, the balance of work changes. I found that design, rather than occurring all up front, occurs continuously during development. As I build the system, I learn how to improve the design. The result of this interaction is a program whose design stays good as development continues.

What's in This Book?

This book is a guide to refactoring; it is written for a professional programmer. My aim is to show you how to do refactoring in a controlled and efficient manner. You will learn to refactor in such a way that you don't introduce bugs into the code but methodically improve its structure.

Traditionally, a book starts with an introduction. I agree with that in principle, but I find it hard to introduce refactoring with a generalized discussion or definitions—so I start with an example. Chapter 1 takes a small program with some common design flaws and refactors it into a program that's easier to understand and change. This will show you both the process of refactoring and a number of useful refactorings. This is the key chapter to read if you want to understand what refactoring really is about.

In Chapter 2, I cover more of the general principles of refactoring, some definitions, and the reasons for doing refactoring. I outline some of the challenges with refactoring. In Chapter 3, Kent Beck helps me describe how to find bad smells in code and how to clean them up with refactorings. Testing plays a very important role in refactoring, so Chapter 4 describes how to build tests into code.

The heart of the book—the catalog of refactorings—takes up the rest of its volume. While this is by no means a comprehensive catalog, it covers the key refactorings that most developers will likely need. It grew from the notes I made when learning about refactoring in the late 1990s, and I still use these notes now as I don't remember them all. When I want to do something, such as *Split Phase* (154), the catalog reminds me how to do it in a safe, step-by-step manner. I hope this is the part of the book that you'll come back to often.

A Web-First Book

The World-Wide Web has made an enormous impact on our society, particularly affecting how we gather information. When I wrote this book, most of the knowledge about software development was transferred through print. Now I gather most of my information online. This has presented a challenge for authors like myself: Is there still a role for books, and what should they look like?

I believe there still is role for books like this—but they need to change. The value of a book is a large body of knowledge put together in a cohesive fashion. In writing this book, I tried to cover many different refactorings and organize them in a consistent and integrated manner.

But that integrated whole is an abstract literary work that, while traditionally represented by a paper book, need not be in the future. Most of the book industry still sees the paper book as the primary representation, and while we've enthusiastically adopted ebooks, they are just electronic representations of an original work based on the structure of a paper book.

With this book, I'm exploring a different approach. The canonical form of this book is its web site or web edition. Access to the web edition is included with the purchase of the print or ebook versions. (See note below about registering your product on InformIT.) The paper book is a selection of material from the web site, arranged in a manner that makes sense for print. It doesn't attempt to include all the refactorings on the web site, particularly since I may well add more refactorings to the canonical web edition in the future. Similarly, the ebook is a different representation of the web book that may not include the same set of refactorings as the printed book—after all, ebooks don't get heavy as I add pages and they can be easily updated after they are bought.

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JavaScript Examples

As in most technical areas of software development, code examples are very important to illustrate the concepts. However, the refactorings look mostly the same in different languages. There will sometimes be particular things that a language forces me to pay attention to, but the core elements of the refactorings remain the same.

I chose JavaScript to illustrate these refactorings, as I felt that this language would be readable by the most amount of people. You shouldn't find it difficult, however, to adapt the refactorings to whatever language you are currently using. I try not to use any of the more complicated bits of the language, so you should be able to follow the refactorings with only a cursory knowledge of JavaScript. My use of JavaScript is certainly not an endorsement of the language.

Although I use JavaScript for my examples, that doesn't mean the techniques in this book are confined to JavaScript. The first edition of this book used Java, and many programmers found it useful even though they never wrote a single Java class. I did toy with illustrating this generality by using a dozen different

languages for the examples, but I felt that would be too confusing for the reader. Still, this book is written for programmers in any language. Outside of the example sections, I'm not making any assumptions about the language. I expect the reader to absorb my general comments and apply them to the language they are using. Indeed, I expect readers to take the JavaScript examples and adapt them to their language.

This means that, apart from discussing specific examples, when I talk about “class,” “module,” “function,” etc., I use those terms in the general programming meaning, not as specific terms of the JavaScript language model.

The fact that I'm using JavaScript as the example language also means that I try to avoid JavaScript styles that will be less familiar to those who aren't regular JavaScript programmers. This is not a “refactoring in JavaScript” book—rather, it's a general refactoring book that happens to use JavaScript. There are many interesting refactorings that are specific to JavaScript (such as refactoring from callbacks, to promises, to `async/await`) but they are out of scope for this book.

Who Should Read This Book?

I've aimed this book at a professional programmer—someone who writes software for a living. The examples and discussion include a lot of code to read and understand. The examples are in JavaScript, but should be applicable to most languages. I would expect a programmer to have some experience to appreciate what's going on with this book, but I don't assume much knowledge.

Although the primary target of this book is a developer seeking to learn about refactoring, this book is also valuable for someone who already understands refactoring—it can be used as a teaching aid. In this book, I've put a lot of effort into explaining how various refactorings work, so an experienced developer can use this material in mentoring their colleagues.

Although it is focused on the code, refactoring has a large impact on the design of system. It is vital for senior designers and architects to understand the principles of refactoring and to use them in their projects. Refactoring is best introduced by a respected and experienced developer. Such a developer can best understand the principles behind refactoring and adapt those principles to the specific workplace. This is particularly true when you are using a language other than JavaScript, because you'll have to adapt the examples I've given to other languages.

Here's how to get the most from this book without reading all of it.

- **If you want to understand what refactoring is**, read Chapter 1—the example should make the process clear.
- **If you want to understand why you should refactor**, read the first two chapters. They will tell you what refactoring is and why you should do it.

- **If you want to find where you should refactor**, read Chapter 3. It tells you the signs that suggest the need for refactoring.
- **If you want to actually do refactoring**, read the first four chapters completely, then skip-read the catalog. Read enough of the catalog to know, roughly, what is in there. You don't have to understand all the details. When you actually need to carry out a refactoring, read the refactoring in detail and use it to help you. The catalog is a reference section, so you probably won't want to read it in one go.

An important part of writing this book was naming the various refactorings. Terminology helps us communicate, so that when one developer advises another to extract some code into a function, or to split some computation into separate phases, both understand the references to *Extract Function* (106) and *Split Phase* (154). This vocabulary also helps in selecting automated refactorings.

Building on a Foundation Laid by Others

I need to say right at the beginning that I owe a big debt with this book—a debt to those whose work in the 1990s developed the field of refactoring. It was learning from their experience that inspired and informed me to write the first edition of this book, and although many years have passed, it's important that I continue to acknowledge the foundation that they laid. Ideally, one of them should have written that first edition, but I ended up being the one with the time and energy.

Two of the leading early proponents of refactoring were **Ward Cunningham** and **Kent Beck**. They used it as a foundation of development in the early days and adapted their development processes to take advantage of it. In particular, it was my collaboration with Kent that showed me the importance of refactoring—an inspiration that led directly to this book.

Ralph Johnson leads a group at the University of Illinois at Urbana-Champaign that is notable for its practical contributions to object technology. Ralph has long been a champion of refactoring, and several of his students did vital early work in this field. **Bill Opdyke** developed the first detailed written work on refactoring in his doctoral thesis. **John Brant** and **Don Roberts** went beyond writing words—they created the first automated refactoring tool, the Refactoring Browser, for refactoring Smalltalk programs.

Many people have advanced the field of refactoring since the first edition of this book. In particular, the work of those who have added automated refactorings to development tools have contributed enormously to making programmers' lives easier. It's easy for me to take it for granted that I can rename a widely used function with a simple key sequence—but that ease relies on the efforts of IDE teams whose work helps us all.

Acknowledgments

Even with all that research to draw on, I still needed a lot of help to write this book. The first edition drew greatly on experience and encouragement from **Kent Beck**. He first introduced me to refactoring, inspired me to start writing notes to record refactorings, and helped form them into finished prose. He came up with the idea of Code Smells. I often feel he would have written the first edition better than I had done—if we wasn't writing the foundation book for Extreme Programming instead.

All the technical book authors I know mention the big debt they owe to technical reviewers. We've all written works with big flaws that were only caught by our peers acting as reviewers. I don't do a lot of technical review work myself, partly because I don't think I'm very good at it, so I have a lot of admiration for those who take it on. There's not even a pittance to be made by reviewing someone else's book, so doing it is a great act of generosity.

When I started serious work on the book, I formed a mailing list of advisors to give me feedback. As I made progress, I sent drafts of new material to this group and asked them for their feedback. I want to thank the following for posting their feedback on the mailing list: **Arlo Belshee**, **Avdi Grimm**, **Beth Anders-Beck**, **Bill Wake**, **Brian Guthrie**, **Brian Marick**, **Chad Wathington**, **Dave Farley**, **David Rice**, **Don Roberts**, **Fred George**, **Giles Alexander**, **Greg Doench**, **Hugo Corbucci**, **Ivan Moore**, **James Shore**, **Jay Fields**, **Jessica Kerr**, **Joshua Kerievsky**, **Kevlin Henney**, **Luciano Ramalho**, **Marcos Brizen**, **Michael Feathers**, **Patrick Kua**, **Pete Hodgson**, **Rebecca Parsons**, and **Trisha Gee**.

Of this group, I'd particularly like to highlight the special help I got on JavaScript from **Beth Anders-Beck**, **James Shore**, and **Pete Hodgson**.

Once I had a pretty complete first draft, I sent it out for further review, because I wanted to have some fresh eyes look at the draft as a whole. **William Chargin** and **Michael Hunger** both delivered incredibly detailed review comments. I also got many useful comments from **Bob Martin** and **Scott Davis**. **Bill Wake** added to his contributions on the mailing list by doing a full review of the first draft.

My colleagues at ThoughtWorks are a constant source of ideas and feedback on my writing. There are innumerable questions, comments, and observations that have fueled the thinking and writing of this book. One of the great things about being an employee at ThoughtWorks is that they allow me to spend considerable time on writing. In particular, I appreciate the regular conversations and ideas I get from **Rebecca Parsons**, our CTO.

At Pearson, **Greg Doench** is my acquisition editor, navigating many issues in getting a book to publication. **Julie Nahil** is my production editor. I was glad to again work with **Dmitry Kirsanov** for copyediting and **Alina Kirsanova** for composition and indexing.

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Chapter 1

Refactoring: A First Example

How do I begin to talk about refactoring? The traditional way is by introducing the history of the subject, broad principles, and the like. When somebody does that at a conference, I get slightly sleepy. My mind starts wandering, with a low-priority background process polling the speaker until they give an example.

The examples wake me up because I can see what is going on. With principles, it is too easy to make broad generalizations—and too hard to figure out how to apply things. An example helps make things clear.

So I'm going to start this book with an example of refactoring. I'll talk about how refactoring works and will give you a sense of the refactoring process. I can then do the usual principles-style introduction in the next chapter.

With any introductory example, however, I run into a problem. If I pick a large program, describing it and how it is refactored is too complicated for a mortal reader to work through. (I tried this with the original book—and ended up throwing away two examples, which were still pretty small but took over a hundred pages each to describe.) However, if I pick a program that is small enough to be comprehensible, refactoring does not look like it is worthwhile.

I'm thus in the classic bind of anyone who wants to describe techniques that are useful for real-world programs. Frankly, it is not worth the effort to do all the refactoring that I'm going to show you on the small program I will be using. But if the code I'm showing you is part of a larger system, then the refactoring becomes important. Just look at my example and imagine it in the context of a much larger system.

The Starting Point

In the first edition of this book, my starting program printed a bill from a video rental store, which may now lead many of you to ask: "What's a video rental store?" Rather than answer that question, I've reskinned the example to something that is both older and still current.

Imagine a company of theatrical players who go out to various events performing plays. Typically, a customer will request a few plays and the company charges them based on the size of the audience and the kind of play they perform. There are currently two kinds of plays that the company performs: tragedies and comedies. As well as providing a bill for the performance, the company gives its customers “volume credits” which they can use for discounts on future performances—think of it as a customer loyalty mechanism.

The performers store data about their plays in a simple JSON file that looks something like this:

plays.json...

```
{
  "hamlet": {"name": "Hamlet", "type": "tragedy"},
  "as-like": {"name": "As You Like It", "type": "comedy"},
  "othello": {"name": "Othello", "type": "tragedy"}
}
```

The data for their bills also comes in a JSON file:

invoices.json...

```
[
  {
    "customer": "BigCo",
    "performances": [
      {
        "playID": "hamlet",
        "audience": 55
      },
      {
        "playID": "as-like",
        "audience": 35
      },
      {
        "playID": "othello",
        "audience": 40
      }
    ]
  }
]
```

The code that prints the bill is this simple function:

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  const format = new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format;
```



```

for (let perf of invoice.performances) {
  const play = plays[perf.playID];
  let thisAmount = 0;

  switch (play.type) {
    case "tragedy":
      thisAmount = 40000;
      if (perf.audience > 30) {
        thisAmount += 1000 * (perf.audience - 30);
      }
      break;
    case "comedy":
      thisAmount = 30000;
      if (perf.audience > 20) {
        thisAmount += 10000 + 500 * (perf.audience - 20);
      }
      thisAmount += 300 * perf.audience;
      break;
    default:
      throw new Error(`unknown type: ${play.type}`);
  }

  // add volume credits
  volumeCredits += Math.max(perf.audience - 30, 0);
  // add extra credit for every ten comedy attendees
  if ("comedy" === play.type) volumeCredits += Math.floor(perf.audience / 5);

  // print line for this order
  result += ` ${play.name}: ${format(thisAmount/100)} (${perf.audience} seats)\n`;
  totalAmount += thisAmount;
}
result += `Amount owed is ${format(totalAmount/100)}\n`;
result += `You earned ${volumeCredits} credits\n`;
return result;
}

```

Running that code on the test data files above results in the following output:

```

Statement for BigCo
Hamlet: $650.00 (55 seats)
As You Like It: $580.00 (35 seats)
Othello: $500.00 (40 seats)
Amount owed is $1,730.00
You earned 47 credits

```

Comments on the Starting Program

What are your thoughts on the design of this program? The first thing I'd say is that it's tolerable as it is—a program so short doesn't require any deep structure to be comprehensible. But remember my earlier point that I have to keep examples

small. Imagine this program on a larger scale—perhaps hundreds of lines long. At that size, a single inline function is hard to understand.

Given that the program works, isn't any statement about its structure merely an aesthetic judgment, a dislike of "ugly" code? After all, the compiler doesn't care whether the code is ugly or clean. But when I change the system, there is a human involved, and humans do care. A poorly designed system is hard to change—because it is difficult to figure out what to change and how these changes will interact with the existing code to get the behavior I want. And if it is hard to figure out what to change, there is a good chance that I will make mistakes and introduce bugs.

Thus, if I'm faced with modifying a program with hundreds of lines of code, I'd rather it be structured into a set of functions and other program elements that allow me to understand more easily what the program is doing. If the program lacks structure, it's usually easier for me to add structure to the program first, and then make the change I need.



When you have to add a feature to a program but the code is not structured in a convenient way, first refactor the program to make it easy to add the feature, then add the feature.

In this case, I have a couple of changes that the users would like to make. First, they want a statement printed in HTML. Consider what impact this change would have. I'm faced with adding conditional statements around every statement that adds a string to the result. That will add a host of complexity to the function. Faced with that, most people prefer to copy the method and change it to emit HTML. Making a copy may not seem too onerous a task, but it sets up all sorts of

problems for the future. Any changes to the charging logic would force me to update both methods—and to ensure they are updated consistently. If I'm writing a program that will never change again, this kind of copy-and-paste is fine. But if it's a long-lived program, then duplication is a menace.

This brings me to a second change. The players are looking to perform more kinds of plays: they hope to add history, pastoral, pastoral-comical, historical-pastoral, tragical-historical, tragical-comical-historical-pastoral, scene individable, and poem unlimited to their repertoire. They haven't exactly decided yet what they want to do and when. This change will affect both the way their plays are charged for and the way volume credits are calculated. As an experienced developer I can be sure that whatever scheme they come up with, they will change it again within six months. After all, when feature requests come, they come not as single spies but in battalions.

Again, that statement method is where the changes need to be made to deal with changes in classification and charging rules. But if I copy statement to `htmlStatement`, I'd need to ensure that any changes are consistent. Furthermore, as the rules

grow in complexity, it's going to be harder to figure out where to make the changes and harder to do them without making a mistake.

Let me stress that it's these changes that drive the need to perform refactoring. If the code works and doesn't ever need to change, it's perfectly fine to leave it alone. It would be nice to improve it, but unless someone needs to understand it, it isn't causing any real harm. Yet as soon as someone does need to understand how that code works, and struggles to follow it, then you have to do something about it.

The First Step in Refactoring

Whenever I do refactoring, the first step is always the same. I need to ensure I have a solid set of tests for that section of code. The tests are essential because even though I will follow refactorings structured to avoid most of the opportunities for introducing bugs, I'm still human and still make mistakes. The larger a program, the more likely it is that my changes will cause something to break inadvertently—in the digital age, frailty's name is software.

Since the statement returns a string, what I do is create a few invoices, give each invoice a few performances of various kinds of plays, and generate the statement strings. I then do a string comparison between the new string and some reference strings that I have hand-checked. I set up all of these tests using a testing framework so I can run them with just a simple keystroke in my development environment. The tests take only a few seconds to run, and as you will see, I run them often.

An important part of the tests is the way they report their results. They either go green, meaning that all the strings are identical to the reference strings, or red, showing a list of failures—the lines that turned out differently. The tests are thus self-checking. It is vital to make tests self-checking. If I don't, I'd end up spending time hand-checking values from the test against values on a desk pad, and that would slow me down. Modern testing frameworks provide all the features needed to write and run self-checking tests.

As I do the refactoring, I'll lean on the tests. I think of them as a bug detector to protect me against my own mistakes. By writing what I want twice, in the code and in the test, I have to make the mistake consistently in both places to fool the detector. By double-checking my work, I reduce the chance of doing something wrong. Although it takes time to build the tests, I end up saving that time, with considerable interest, by spending less time debugging. This is such an important part of refactoring that I devote a full chapter to it (*Building Tests* (85)).

Before you start refactoring, make sure you have a solid suite of tests. These tests must be self-checking.



Decomposing the statement Function

When refactoring a long function like this, I mentally try to identify points that separate different parts of the overall behavior. The first chunk that leaps to my eye is the switch statement in the middle.

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  const format = new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format;
  for (let perf of invoice.performances) {
    const play = plays[perf.playID];
    let thisAmount = 0;

    switch (play.type) {
      case "tragedy":
        thisAmount = 40000;
        if (perf.audience > 30) {
          thisAmount += 1000 * (perf.audience - 30);
        }
        break;
      case "comedy":
        thisAmount = 30000;
        if (perf.audience > 20) {
          thisAmount += 10000 + 500 * (perf.audience - 20);
        }
        thisAmount += 300 * perf.audience;
        break;
      default:
        throw new Error(`unknown type: ${play.type}`);
    }

    // add volume credits
    volumeCredits += Math.max(perf.audience - 30, 0);
    // add extra credit for every ten comedy attendees
    if ("comedy" === play.type) volumeCredits += Math.floor(perf.audience / 5);

    // print line for this order
    result += ` ${play.name}: ${format(thisAmount/100)} (${perf.audience} seats)\n`;
    totalAmount += thisAmount;
  }
  result += `Amount owed is ${format(totalAmount/100)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

As I look at this chunk, I conclude that it's calculating the charge for one performance. That conclusion is a piece of insight about the code. But as Ward Cunningham puts it, this understanding is in my head—a notoriously volatile form of storage. I need to persist it by moving it from my head back into the code itself. That way, should I come back to it later, the code will tell me what it's doing—I don't have to figure it out again.

The way to put that understanding into code is to turn that chunk of code into its own function, naming it after what it does—something like `amountFor(aPerformance)`. When I want to turn a chunk of code into a function like this, I have a procedure for doing it that minimizes my chances of getting it wrong. I wrote down this procedure and, to make it easy to reference, named it *Extract Function (106)*.

First, I need to look in the fragment for any variables that will no longer be in scope once I've extracted the code into its own function. In this case, I have three: `perf`, `play`, and `thisAmount`. The first two are used by the extracted code, but not modified, so I can pass them in as parameters. Modified variables need more care. Here, there is only one, so I can return it. I can also bring its initialization inside the extracted code. All of which yields this:

function statement...

```
function amountFor(perf, play) {
  let thisAmount = 0;
  switch (play.type) {
    case "tragedy":
      thisAmount = 40000;
      if (perf.audience > 30) {
        thisAmount += 1000 * (perf.audience - 30);
      }
      break;
    case "comedy":
      thisAmount = 30000;
      if (perf.audience > 20) {
        thisAmount += 10000 + 500 * (perf.audience - 20);
      }
      thisAmount += 300 * perf.audience;
      break;
    default:
      throw new Error(`unknown type: ${play.type}`);
  }
  return thisAmount;
}
```

When I use a header like *"function someName..."* in italics for some code, that means that the following code is within the scope of the function, file, or class named in the header. There is usually other code within that scope that I won't show, as I'm not discussing it at the moment.

The original statement code now calls this function to populate `thisAmount`:

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  const format = new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format;
  for (let perf of invoice.performances) {
    const play = plays[perf.playID];
    let thisAmount = amountFor(perf, play);

    // add volume credits
    volumeCredits += Math.max(perf.audience - 30, 0);
    // add extra credit for every ten comedy attendees
    if ("comedy" === play.type) volumeCredits += Math.floor(perf.audience / 5);

    // print line for this order
    result += ` ${play.name}: ${format(thisAmount/100)} (${perf.audience} seats)\n`;
    totalAmount += thisAmount;
  }
  result += `Amount owed is ${format(totalAmount/100)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

Once I've made this change, I immediately compile and test to see if I've broken anything. It's an important habit to test after every refactoring, however simple. Mistakes are easy to make—at least, I find them easy to make. Testing after each change means that when I make a mistake, I only have a small change to consider in order to spot the error, which makes it far easier to find and fix. This is the essence of the refactoring process: small changes and testing after each change. If I try to do too much, making a mistake will force me into a tricky debugging episode that can take a long time. Small changes, enabling a tight feedback loop, are the key to avoiding that mess.

I use *compile* here to mean doing whatever is needed to make the JavaScript executable. Since JavaScript is directly executable, that may mean nothing, but in other cases it may mean moving code to an output directory and/or using a processor such as Babel [babel].



Refactoring changes the programs in small steps, so if you make a mistake, it is easy to find where the bug is.

This being JavaScript, I can extract `amountFor` into a nested function of `statement`. This is helpful as it means I don't have to pass data that's inside the scope of the containing function to the newly extracted function. That doesn't make a difference in this case, but it's one less issue to deal with.

In this case the tests passed, so my next step is to commit the change to my local version control system. I use a version control system, such as git or mercurial, that allows me to make private commits. I commit after each successful refactoring, so I can easily get back to a working state should I mess up later. I then squash changes into more significant commits before I push the changes to a shared repository.

Extract Function (106) is a common refactoring to automate. If I was programming in Java, I would have instinctively reached for the key sequence for my IDE to perform this refactoring. As I write this, there is no such robust support for this refactoring in JavaScript tools, so I have to do this manually. It's not hard, although I have to be careful with those locally scoped variables.

Once I've used *Extract Function (106)*, I take a look at what I've extracted to see if there are any quick and easy things I can do to clarify the extracted function. The first thing I do is rename some of the variables to make them clearer, such as changing `thisAmount` to `result`.

function statement...

```
function amountFor(perf, play) {
  let result = 0;
  switch (play.type) {
    case "tragedy":
      result = 40000;
      if (perf.audience > 30) {
        result += 1000 * (perf.audience - 30);
      }
      break;
    case "comedy":
      result = 30000;
      if (perf.audience > 20) {
        result += 10000 + 500 * (perf.audience - 20);
      }
      result += 300 * perf.audience;
      break;
    default:
      throw new Error(`unknown type: ${play.type}`);
  }
  return result;
}
```

It's my coding standard to always call the return value from a function "result". That way I always know its role. Again, I compile, test, and commit. Then I move onto the first argument.

function statement...

```
function amountFor(aPerformance, play) {
  let result = 0;
  switch (play.type) {
    case "tragedy":
      result = 40000;
      if (aPerformance.audience > 30) {
        result += 1000 * (aPerformance.audience - 30);
      }
      break;
    case "comedy":
      result = 30000;
      if (aPerformance.audience > 20) {
        result += 10000 + 500 * (aPerformance.audience - 20);
      }
      result += 300 * aPerformance.audience;
      break;
    default:
      throw new Error(`unknown type: ${play.type}`);
  }
  return result;
}
```

Again, this is following my coding style. With a dynamically typed language such as JavaScript, it's useful to keep track of types—hence, my default name for a parameter includes the type name. I use an indefinite article with it unless there is some specific role information to capture in the name. I learned this convention from Kent Beck [Beck SBPP] and continue to find it helpful.



Any fool can write code that a computer can understand. Good programmers write code that humans can understand.

Is this renaming worth the effort? Absolutely. Good code should clearly communicate what it is doing, and variable names are a key to clear code. Never be afraid to change names to improve clarity. With good find-and-replace tools, it is usually not difficult; testing, and static typing in a language that supports

it, will highlight any occurrences you miss. And with automated refactoring tools, it's trivial to rename even widely used functions.

The next item to consider for renaming is the `play` parameter, but I have a different fate for that.

Removing the `play` Variable

As I consider the parameters to `amountFor`, I look to see where they come from. `aPerformance` comes from the loop variable, so naturally changes with each iteration

through the loop. But `play` is computed from the performance, so there's no need to pass it in as a parameter at all—I can just recalculate it within `amountFor`. When I'm breaking down a long function, I like to get rid of variables like `play`, because temporary variables create a lot of locally scoped names that complicate extractions. The refactoring I will use here is *Replace Temp with Query* (178).

I begin by extracting the right-hand side of the assignment into a function.

function statement...

```
function playFor(aPerformance) {
  return plays[aPerformance.playID];
}
```

top level...

```
function statement(invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  const format = new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format;
  for (let perf of invoice.performances) {
    const play = playFor(perf);
    let thisAmount = amountFor(perf, play);

    // add volume credits
    volumeCredits += Math.max(perf.audience - 30, 0);
    // add extra credit for every ten comedy attendees
    if ("comedy" === play.type) volumeCredits += Math.floor(perf.audience / 5);

    // print line for this order
    result += ` ${play.name}: ${format(thisAmount/100)} (${perf.audience} seats)\n`;
    totalAmount += thisAmount;
  }
  result += `Amount owed is ${format(totalAmount/100)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

I compile-test-commit, and then use *Inline Variable* (123).

top level...

```
function statement(invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  const format = new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format;
```

```

for (let perf of invoice.performances) {
  const play = playFor(perf);
  let thisAmount = amountFor(perf, playFor(perf));

  // add volume credits
  volumeCredits += Math.max(perf.audience - 30, 0);
  // add extra credit for every ten comedy attendees
  if ("comedy" === playFor(perf).type) volumeCredits += Math.floor(perf.audience / 5);

  // print line for this order
  result += ` ${playFor(perf).name}: ${format(thisAmount/100)} (${perf.audience} seats)\n`;
  totalAmount += thisAmount;
}
result += `Amount owed is ${format(totalAmount/100)}\n`;
result += `You earned ${volumeCredits} credits\n`;
return result;

```

I compile-test-commit. With that inlined, I can then apply *Change Function Declaration (124)* to `amountFor` to remove the `play` parameter. I do this in two steps. First, I use the new function inside `amountFor`.

function statement...

```

function amountFor(aPerformance, play) {
  let result = 0;
  switch (playFor(aPerformance).type) {
    case "tragedy":
      result = 40000;
      if (aPerformance.audience > 30) {
        result += 1000 * (aPerformance.audience - 30);
      }
      break;
    case "comedy":
      result = 30000;
      if (aPerformance.audience > 20) {
        result += 10000 + 500 * (aPerformance.audience - 20);
      }
      result += 300 * aPerformance.audience;
      break;
    default:
      throw new Error(`unknown type: ${playFor(aPerformance).type}`);
  }
  return result;
}

```

I compile-test-commit, and then delete the parameter.

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  const format = new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format;
  for (let perf of invoice.performances) {
    let thisAmount = amountFor(perf, playFor(perf));

    // add volume credits
    volumeCredits += Math.max(perf.audience - 30, 0);
    // add extra credit for every ten comedy attendees
    if ("comedy" === playFor(perf).type) volumeCredits += Math.floor(perf.audience / 5);

    // print line for this order
    result += ` ${playFor(perf).name}: ${format(thisAmount/100)} (${perf.audience} seats)\n`;
    totalAmount += thisAmount;
  }
  result += `Amount owed is ${format(totalAmount/100)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

function statement...

```
function amountFor(aPerformance, play) {
  let result = 0;
  switch (playFor(aPerformance).type) {
    case "tragedy":
      result = 40000;
      if (aPerformance.audience > 30) {
        result += 1000 * (aPerformance.audience - 30);
      }
      break;
    case "comedy":
      result = 30000;
      if (aPerformance.audience > 20) {
        result += 10000 + 500 * (aPerformance.audience - 20);
      }
      result += 300 * aPerformance.audience;
      break;
    default:
      throw new Error(`unknown type: ${playFor(aPerformance).type}`);
  }
  return result;
}
```

And compile-test-commit again.

This refactoring alarms some programmers. Previously, the code to look up the play was executed once in each loop iteration; now, it's executed thrice. I'll talk about the interplay of refactoring and performance later, but for the moment I'll just observe that this change is unlikely to significantly affect performance, and even if it were, it is much easier to improve the performance of a well-factored code base.

The great benefit of removing local variables is that it makes it much easier to do extractions, since there is less local scope to deal with. Indeed, usually I'll take out local variables before I do any extractions.

Now that I'm done with the arguments to `amountFor`, I look back at where it's called. It's being used to set a temporary variable that's not updated again, so I apply *Inline Variable (123)*.

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  const format = new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format;

  for (let perf of invoice.performances) {

    // add volume credits
    volumeCredits += Math.max(perf.audience - 30, 0);
    // add extra credit for every ten comedy attendees
    if ("comedy" === playFor(perf).type) volumeCredits += Math.floor(perf.audience / 5);

    // print line for this order
    result += ` ${playFor(perf).name}: ${format(amountFor(perf)/100)} (${perf.audience} seats)\n`;
    totalAmount += amountFor(perf);
  }
  result += `Amount owed is ${format(totalAmount/100)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

Extracting Volume Credits

Here's the current state of the `statement` function body:

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  const format = new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format;
```

```

for (let perf of invoice.performances) {

  // add volume credits
  volumeCredits += Math.max(perf.audience - 30, 0);
  // add extra credit for every ten comedy attendees
  if ("comedy" === playFor(perf).type) volumeCredits += Math.floor(perf.audience / 5);

  // print line for this order
  result += ` ${playFor(perf).name}: ${format(amountFor(perf)/100)} (${perf.audience} seats)\n`;
  totalAmount += amountFor(perf);
}
result += `Amount owed is ${format(totalAmount/100)}\n`;
result += `You earned ${volumeCredits} credits\n`;
return result;

```

Now I get the benefit from removing the play variable as it makes it easier to extract the volume credits calculation by removing one of the locally scoped variables.

I still have to deal with the other two. Again, `perf` is easy to pass in, but `volumeCredits` is a bit more tricky as it is an accumulator updated in each pass of the loop. So my best bet is to initialize a shadow of it inside the extracted function and return it.

function statement...

```

function volumeCreditsFor(perf) {
  let volumeCredits = 0;
  volumeCredits += Math.max(perf.audience - 30, 0);
  if ("comedy" === playFor(perf).type) volumeCredits += Math.floor(perf.audience / 5);
  return volumeCredits;
}

```

top level...

```

function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  const format = new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format;
  for (let perf of invoice.performances) {
    volumeCredits += volumeCreditsFor(perf);

    // print line for this order
    result += ` ${playFor(perf).name}: ${format(amountFor(perf)/100)} (${perf.audience} seats)\n`;
    totalAmount += amountFor(perf);
  }
  result += `Amount owed is ${format(totalAmount/100)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}

```

I remove the unnecessary (and, in this case, downright misleading) comment.

I compile-test-commit that, and then rename the variables inside the new function.

function statement...

```
function volumeCreditsFor(aPerformance) {
  let result = 0;
  result += Math.max(aPerformance.audience - 30, 0);
  if ("comedy" === playFor(aPerformance).type) result += Math.floor(aPerformance.audience / 5);
  return result;
}
```

I've shown it in one step, but as before I did the renames one at a time, with a compile-test-commit after each.

Removing the format Variable

Let's look at the main statement method again:

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  const format = new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format;
  for (let perf of invoice.performances) {
    volumeCredits += volumeCreditsFor(perf);

    // print line for this order
    result += ` ${playFor(perf).name}: ${format(amountFor(perf)/100)} (${perf.audience} seats)\n`;
    totalAmount += amountFor(perf);
  }
  result += `Amount owed is ${format(totalAmount/100)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

As I suggested before, temporary variables can be a problem. They are only useful within their own routine, and therefore they encourage long, complex routines. My next move, then, is to replace some of them. The easiest one is `format`. This is a case of assigning a function to a temp, which I prefer to replace with a declared function.

function statement...

```
function format(aNumber) {
  return new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format(aNumber);
}
```

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  for (let perf of invoice.performances) {
    volumeCredits += volumeCreditsFor(perf);

    // print line for this order
    result += ` ${playFor(perf).name}: ${format(amountFor(perf)/100)} (${perf.audience} seats)\n`;
    totalAmount += amountFor(perf);
  }
  result += `Amount owed is ${format(totalAmount/100)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

Although changing a function variable to a declared function is a refactoring, I haven't named it and included it in the catalog. There are many refactorings that I didn't feel important enough for that. This one is both simple to do and relatively rare, so I didn't think it was worthwhile.

I'm not keen on the name—"format" doesn't really convey enough of what it's doing. "formatAsUSD" would be a bit too long-winded since it's being used in a string template, particularly within this small scope. I think the fact that it's formatting a currency amount is the thing to highlight here, so I pick a name that suggests that and apply *Change Function Declaration (124)*.

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;
  for (let perf of invoice.performances) {
    volumeCredits += volumeCreditsFor(perf);

    // print line for this order
    result += ` ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
    totalAmount += amountFor(perf);
  }
  result += `Amount owed is ${usd(totalAmount)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

function statement...

```
function usd(aNumber) {
  return new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format(aNumber/100);
}
```

Naming is both important and tricky. Breaking a large function into smaller ones only adds value if the names are good. With good names, I don't have to read the body of the function to see what it does. But it's hard to get names right the first time, so I use the best name I can think of for the moment, and don't hesitate to rename it later. Often, it takes a second pass through some code to realize what the best name really is.

As I'm changing the name, I also move the duplicated division by 100 into the function. Storing money as integer cents is a common approach—it avoids the dangers of storing fractional monetary values as floats but allows me to use arithmetic operators. Whenever I want to display such a penny-integer number, however, I need a decimal, so my formatting function should take care of the division.

Removing Total Volume Credits

My next target variable is `volumeCredits`. This is a trickier case, as it's built up during the iterations of the loop. My first move, then, is to use *Split Loop* (227) to separate the accumulation of `volumeCredits`.

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let volumeCredits = 0;
  let result = `Statement for ${invoice.customer}\n`;

  for (let perf of invoice.performances) {

    // print line for this order
    result += ` ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
    totalAmount += amountFor(perf);
  }
  for (let perf of invoice.performances) {
    volumeCredits += volumeCreditsFor(perf);
  }

  result += `Amount owed is ${usd(totalAmount)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

With that done, I can use *Slide Statements* (223) to move the declaration of the variable next to the loop.

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let result = `Statement for ${invoice.customer}\n`;
  for (let perf of invoice.performances) {

    // print line for this order
    result += ` ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
    totalAmount += amountFor(perf);
  }
  let volumeCredits = 0;
  for (let perf of invoice.performances) {
    volumeCredits += volumeCreditsFor(perf);
  }
  result += `Amount owed is ${usd(totalAmount)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

Gathering together everything that updates the `volumeCredits` variable makes it easier to do *Replace Temp with Query* (178). As before, the first step is to apply *Extract Function* (106) to the overall calculation of the variable.

function statement...

```
function totalVolumeCredits() {
  let volumeCredits = 0;
  for (let perf of invoice.performances) {
    volumeCredits += volumeCreditsFor(perf);
  }
  return volumeCredits;
}
```

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let result = `Statement for ${invoice.customer}\n`;
  for (let perf of invoice.performances) {

    // print line for this order
    result += ` ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
    totalAmount += amountFor(perf);
  }
  let volumeCredits = totalVolumeCredits();
  result += `Amount owed is ${usd(totalAmount)}\n`;
  result += `You earned ${volumeCredits} credits\n`;
  return result;
}
```

Once everything is extracted, I can apply *Inline Variable* (123):

top level...

```
function statement (invoice, plays) {
  let totalAmount = 0;
  let result = `Statement for ${invoice.customer}\n`;
  for (let perf of invoice.performances) {

    // print line for this order
    result += ` ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
    totalAmount += amountFor(perf);
  }

  result += `Amount owed is ${usd(totalAmount)}\n`;
  result += `You earned ${totalVolumeCredits()} credits\n`;
  return result;
}
```

Let me pause for a bit to talk about what I’ve just done here. Firstly, I know readers will again be worrying about performance with this change, as many people are wary of repeating a loop. But most of the time, rerunning a loop like this has a negligible effect on performance. If you timed the code before and after this refactoring, you would probably not notice any significant change in speed—and that’s usually the case. Most programmers, even experienced ones, are poor judges of how code actually performs. Many of our intuitions are broken by clever compilers, modern caching techniques, and the like. The performance of software usually depends on just a few parts of the code, and changes anywhere else don’t make an appreciable difference.

But “mostly” isn’t the same as “alwaysly.” Sometimes a refactoring will have a significant performance implication. Even then, I usually go ahead and do it, because it’s much easier to tune the performance of well-factored code. If I introduce a significant performance issue during refactoring, I spend time on performance tuning afterwards. It may be that this leads to reversing some of the refactoring I did earlier—but most of the time, due to the refactoring, I can apply a more effective performance-tuning enhancement instead. I end up with code that’s both clearer and faster.

So, my overall advice on performance with refactoring is: Most of the time you should ignore it. If your refactoring introduces performance slow-downs, finish refactoring first and do performance tuning afterwards.

The second aspect I want to call your attention to is how small the steps were to remove `volumeCredits`. Here are the four steps, each followed by compiling, testing, and committing to my local source code repository:

- *Split Loop (227)* to isolate the accumulation
- *Slide Statements (223)* to bring the initializing code next to the accumulation
- *Extract Function (106)* to create a function for calculating the total
- *Inline Variable (123)* to remove the variable completely

I confess I don't always take quite as short steps as these—but whenever things get difficult, my first reaction is to take shorter steps. In particular, should a test fail during a refactoring, if I can't immediately see and fix the problem, I'll revert to my last good commit and redo what I just did with smaller steps. That works because I commit so frequently and because small steps are the key to moving quickly, particularly when working with difficult code.

I then repeat that sequence to remove `totalAmount`. I start by splitting the loop (compile-test-commit), then I slide the variable initialization (compile-test-commit), and then I extract the function. There is a wrinkle here: The best name for the function is “`totalAmount`”, but that's the name of the variable, and I can't have both at the same time. So I give the new function a random name when I extract it (and compile-test-commit).

function statement...

```
function appleSauce() {
  let totalAmount = 0;
  for (let perf of invoice.performances) {
    totalAmount += amountFor(perf);
  }
  return totalAmount;
}
```

top level...

```
function statement (invoice, plays) {
  let result = `Statement for ${invoice.customer}\n`;
  for (let perf of invoice.performances) {
    result += ` ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
  }
  let totalAmount = appleSauce();

  result += `Amount owed is ${usd(totalAmount)}\n`;
  result += `You earned ${totalVolumeCredits()} credits\n`;
  return result;
}
```

Then I inline the variable (compile-test-commit) and rename the function to something more sensible (compile-test-commit).

top level...

```
function statement (invoice, plays) {
  let result = `Statement for ${invoice.customer}\n`;
  for (let perf of invoice.performances) {
    result += ` ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
  }
  result += `Amount owed is ${usd(totalAmount())}\n`;
  result += `You earned ${totalVolumeCredits()} credits\n`;
  return result;
}
```

function statement...

```
function totalAmount() {
  let totalAmount = 0;
  for (let perf of invoice.performances) {
    totalAmount += amountFor(perf);
  }
  return totalAmount;
}
```

I also take the opportunity to change the names inside my extracted functions to adhere to my convention.

function statement...

```
function totalAmount() {
  let result = 0;
  for (let perf of invoice.performances) {
    result += amountFor(perf);
  }
  return result;
}
function totalVolumeCredits() {
  let result = 0;
  for (let perf of invoice.performances) {
    result += volumeCreditsFor(perf);
  }
  return result;
}
```

Status: Lots of Nested Functions

Now is a good time to pause and take a look at the overall state of the code:

```
function statement (invoice, plays) {
  let result = `Statement for ${invoice.customer}\n`;
  for (let perf of invoice.performances) {
    result += `  ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
  }
  result += `Amount owed is ${usd(totalAmount())}\n`;
  result += `You earned ${totalVolumeCredits()} credits\n`;
  return result;
}

function totalAmount() {
  let result = 0;
  for (let perf of invoice.performances) {
    result += amountFor(perf);
  }
  return result;
}
```

```

function totalVolumeCredits() {
  let result = 0;
  for (let perf of invoice.performances) {
    result += volumeCreditsFor(perf);
  }
  return result;
}
function usd(aNumber) {
  return new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format(aNumber/100);
}
function volumeCreditsFor(aPerformance) {
  let result = 0;
  result += Math.max(aPerformance.audience - 30, 0);
  if ("comedy" === playFor(aPerformance).type) result += Math.floor(aPerformance.audience / 5);
  return result;
}
function playFor(aPerformance) {
  return plays[aPerformance.playID];
}
function amountFor(aPerformance) {
  let result = 0;
  switch (playFor(aPerformance).type) {
    case "tragedy":
      result = 40000;
      if (aPerformance.audience > 30) {
        result += 1000 * (aPerformance.audience - 30);
      }
      break;
    case "comedy":
      result = 30000;
      if (aPerformance.audience > 20) {
        result += 10000 + 500 * (aPerformance.audience - 20);
      }
      result += 300 * aPerformance.audience;
      break;
    default:
      throw new Error(`unknown type: ${playFor(aPerformance).type}`);
  }
  return result;
}
}

```

The structure of the code is much better now. The top-level statement function is now just seven lines of code, and all it does is laying out the printing of the statement. All the calculation logic has been moved out to a handful of supporting functions. This makes it easier to understand each individual calculation as well as the overall flow of the report.

Splitting the Phases of Calculation and Formatting

So far, my refactoring has focused on adding enough structure to the function so that I can understand it and see it in terms of its logical parts. This is often the case early in refactoring. Breaking down complicated chunks into small pieces is important, as is naming things well. Now, I can begin to focus more on the functionality change I want to make—specifically, providing an HTML version of this statement. In many ways, it's now much easier to do. With all the calculation code split out, all I have to do is write an HTML version of the seven lines of code at the top. The problem is that these broken-out functions are nested within the textual statement method, and I don't want to copy and paste them into a new function, however well organized. I want the same calculation functions to be used by the text and HTML versions of the statement.

There are various ways to do this, but one of my favorite techniques is *Split Phase (154)*. My aim here is to divide the logic into two parts: one that calculates the data required for the statement, the other that renders it into text or HTML. The first phase creates an intermediate data structure that it passes to the second.

I start a *Split Phase (154)* by applying *Extract Function (106)* to the code that makes up the second phase. In this case, that's the statement printing code, which is in fact the entire content of statement. This, together with all the nested functions, goes into its own top-level function which I call `renderPlainText`.

```
function statement (invoice, plays) {
  return renderPlainText(invoice, plays);
}

function renderPlainText(invoice, plays) {
  let result = `Statement for ${invoice.customer}\n`;
  for (let perf of invoice.performances) {
    result += ` ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
  }
  result += `Amount owed is ${usd(totalAmount())}\n`;
  result += `You earned ${totalVolumeCredits()} credits\n`;
  return result;
}

function totalAmount() {...}
function totalVolumeCredits() {...}
function usd(aNumber) {...}
function volumeCreditsFor(aPerformance) {...}
function playFor(aPerformance) {...}
function amountFor(aPerformance) {...}
```

I do my usual compile-test-commit, then create an object that will act as my intermediate data structure between the two phases. I pass this data object in as an argument to `renderPlainText` (compile-test-commit).

```
function statement (invoice, plays) {
  const statementData = {};
  return renderPlainText(statementData, invoice, plays);
}

function renderPlainText(data, invoice, plays) {
  let result = `Statement for ${invoice.customer}\n`;
  for (let perf of invoice.performances) {
    result += ` ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
  }
  result += `Amount owed is ${usd(totalAmount())}\n`;
  result += `You earned ${totalVolumeCredits()} credits\n`;
  return result;

  function totalAmount() {...}
  function totalVolumeCredits() {...}
  function usd(aNumber) {...}
  function volumeCreditsFor(aPerformance) {...}
  function playFor(aPerformance) {...}
  function amountFor(aPerformance) {...}
}
```

I now examine the other arguments used by `renderPlainText`. I want to move the data that comes from them into the intermediate data structure, so that all the calculation code moves into the statement function and `renderPlainText` operates solely on data passed to it through the data parameter.

My first move is to take the customer and add it to the intermediate object (compile-test-commit).

```
function statement (invoice, plays) {
  const statementData = {};
  statementData.customer = invoice.customer;
  return renderPlainText(statementData, invoice, plays);
}

function renderPlainText(data, invoice, plays) {
  let result = `Statement for ${data.customer}\n`;
  for (let perf of invoice.performances) {
    result += ` ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
  }
  result += `Amount owed is ${usd(totalAmount())}\n`;
  result += `You earned ${totalVolumeCredits()} credits\n`;
  return result;
}
```

Similarly, I add the performances, which allows me to delete the invoice parameter to `renderPlainText` (compile-test-commit).

top level...

```
function statement(invoice, plays) {
  const statementData = {};
  statementData.customer = invoice.customer;
  statementData.performances = invoice.performances;
  return renderPlainText(statementData, invoice, plays);
}

function renderPlainText(data, plays) {
  let result = `Statement for ${data.customer}\n`;
  for (let perf of data.performances) {
    result += `  ${playFor(perf).name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
  }
  result += `Amount owed is ${usd(totalAmount())}\n`;
  result += `You earned ${totalVolumeCredits()} credits\n`;
  return result;
}
```

function renderPlainText...

```
function totalAmount() {
  let result = 0;
  for (let perf of data.performances) {
    result += amountFor(perf);
  }
  return result;
}

function totalVolumeCredits() {
  let result = 0;
  for (let perf of data.performances) {
    result += volumeCreditsFor(perf);
  }
  return result;
}
```

Now I'd like the play name to come from the intermediate data. To do this, I need to enrich the performance record with data from the play (compile-test-commit).


```
function statement (invoice, plays) {
  const statementData = {};
  statementData.customer = invoice.customer;
  statementData.performances = invoice.performances.map(enrichPerformance);
  return renderPlainText(statementData, plays);

  function enrichPerformance(aPerformance) {
    const result = Object.assign({}, aPerformance);
    return result;
  }
}
```

At the moment, I'm just making a copy of the performance object, but I'll shortly add data to this new record. I take a copy because I don't want to modify the data passed into the function. I prefer to treat data as immutable as much as I can—mutable state quickly becomes something rotten.

The idiom `result = Object.assign({}, aPerformance)` looks very odd to people unfamiliar to JavaScript. It performs a shallow copy. I'd prefer to have a function for this, but it's one of those cases where the idiom is so baked into JavaScript usage that writing my own function would look out of place for JavaScript programmers.

Now I have a spot for the `play`, I need to add it. To do that, I need to apply *Move Function (198)* to `playFor` and `statement` (`compile-test-commit`).

function statement...

```
function enrichPerformance(aPerformance) {
  const result = Object.assign({}, aPerformance);
  result.play = playFor(result);
  return result;
}

function playFor(aPerformance) {
  return plays[aPerformance.playID];
}
```

I then replace all the references to `playFor` in `renderPlainText` to use the data instead (`compile-test-commit`).

function renderPlainText...

```

    let result = `Statement for ${data.customer}\n`;
    for (let perf of data.performances) {
        result += ` ${perf.play.name}: ${usd(amountFor(perf))} (${perf.audience} seats)\n`;
    }
    result += `Amount owed is ${usd(totalAmount())}\n`;
    result += `You earned ${totalVolumeCredits()} credits\n`;
    return result;

function volumeCreditsFor(aPerformance) {
    let result = 0;
    result += Math.max(aPerformance.audience - 30, 0);
    if ("comedy" === aPerformance.play.type) result += Math.floor(aPerformance.audience / 5);
    return result;
}

function amountFor(aPerformance) {
    let result = 0;
    switch (aPerformance.play.type) {
        case "tragedy":
            result = 40000;
            if (aPerformance.audience > 30) {
                result += 1000 * (aPerformance.audience - 30);
            }
            break;
        case "comedy":
            result = 30000;
            if (aPerformance.audience > 20) {
                result += 10000 + 500 * (aPerformance.audience - 20);
            }
            result += 300 * aPerformance.audience;
            break;
        default:
            throw new Error(`unknown type: ${aPerformance.play.type}`);
    }
    return result;
}

```

I then move `amountFor` in a similar way (`compile-test-commit`).

function statement...

```

function enrichPerformance(aPerformance) {
    const result = Object.assign({}, aPerformance);
    result.play = playFor(result);
    result.amount = amountFor(result);
    return result;
}

function amountFor(aPerformance) {...}

```

function renderPlainText...

```
let result = `Statement for ${data.customer}\n`;
for (let perf of data.performances) {
  result += ` ${perf.play.name}: ${usd(perf.amount)} (${perf.audience} seats)\n`;
}
result += `Amount owed is ${usd(totalAmount())}\n`;
result += `You earned ${totalVolumeCredits()} credits\n`;
return result;

function totalAmount() {
  let result = 0;
  for (let perf of data.performances) {
    result += perf.amount;
  }
  return result;
}
```

Next, I move the volume credits calculation (compile-test-commit).

function statement...

```
function enrichPerformance(aPerformance) {
  const result = Object.assign({}, aPerformance);
  result.play = playFor(result);
  result.amount = amountFor(result);
  result.volumeCredits = volumeCreditsFor(result);
  return result;
}

function volumeCreditsFor(aPerformance) {...}
```

function renderPlainText...

```
function totalVolumeCredits() {
  let result = 0;
  for (let perf of data.performances) {
    result += perf.volumeCredits;
  }
  return result;
}
```

Finally, I move the two calculations of the totals.

function statement...

```
const statementData = {};
statementData.customer = invoice.customer;
statementData.performances = invoice.performances.map(enrichPerformance);
statementData.totalAmount = totalAmount(statementData);
statementData.totalVolumeCredits = totalVolumeCredits(statementData);
return renderPlainText(statementData, plays);

function totalAmount(data) {...}
  function totalVolumeCredits(data) {...}
```

function renderPlainText...

```
let result = `Statement for ${data.customer}\n`;
for (let perf of data.performances) {
  result += ` ${perf.play.name}: ${usd(perf.amount)} (${perf.audience} seats)\n`;
}
result += `Amount owed is ${usd(data.totalAmount)}\n`;
result += `You earned ${data.totalVolumeCredits} credits\n`;
return result;
```

Although I could have modified the bodies of these totals functions to use the `statementData` variable (as it's within scope), I prefer to pass the explicit parameter.

And, once I'm done with `compile-test-commit` after the move, I can't resist a couple quick shots of *Replace Loop with Pipeline* (231).

function renderPlainText...

```
function totalAmount(data) {
  return data.performances
    .reduce((total, p) => total + p.amount, 0);
}
function totalVolumeCredits(data) {
  return data.performances
    .reduce((total, p) => total + p.volumeCredits, 0);
}
```

I now extract all the first-phase code into its own function (`compile-test-commit`).

top level...

```
function statement(invoice, plays) {
  return renderPlainText(createStatementData(invoice, plays));
}

function createStatementData(invoice, plays) {
  const statementData = {};
  statementData.customer = invoice.customer;
  statementData.performances = invoice.performances.map(enrichPerformance);
  statementData.totalAmount = totalAmount(statementData);
  statementData.totalVolumeCredits = totalVolumeCredits(statementData);
  return statementData;
}
```

Since it's clearly separate now, I move it to its own file (and alter the name of the returned result to match my usual convention).

statement.js...

```
import createStatementData from './createStatementData.js';
```

createStatementData.js...

```
export default function createStatementData(invoice, plays) {
  const result = {};
  result.customer = invoice.customer;
  result.performances = invoice.performances.map(enrichPerformance);
  result.totalAmount = totalAmount(result);
  result.totalVolumeCredits = totalVolumeCredits(result);
  return result;

  function enrichPerformance(aPerformance) {...}
  function playFor(aPerformance) {...}
  function amountFor(aPerformance) {...}
  function volumeCreditsFor(aPerformance) {...}
  function totalAmount(data) {...}
  function totalVolumeCredits(data) {...}
```

One final swing of compile-test-commit—and now it's easy to write an HTML version.

statement.js...

```
function htmlStatement (invoice, plays) {
  return renderHtml(createStatementData(invoice, plays));
}

function renderHtml (data) {
  let result = `<h1>Statement for ${data.customer}</h1>\n`;
  result += "<table>\n";
  result += "<tr><th>play</th><th>seats</th><th>cost</th></tr>";
  for (let perf of data.performances) {
    result += `<tr><td>${perf.play.name}</td><td>${perf.audience}</td>`;
    result += `<td>${usd(perf.amount)}</td></tr>\n`;
  }
  result += "</table>\n";
  result += `<p>Amount owed is <em>${usd(data.totalAmount)}</em></p>\n`;
  result += `<p>You earned <em>${data.totalVolumeCredits}</em> credits</p>\n`;
  return result;
}

function usd(aNumber) {...}
```

(I moved usd to the top level, so that renderHtml could use it.)

Status: Separated into Two Files (and Phases)

This is a good moment to take stock again and think about where the code is now. I have two files of code.

statement.js

```

import createStatementData from './createStatementData.js';
function statement (invoice, plays) {
  return renderPlainText(createStatementData(invoice, plays));
}
function renderPlainText(data, plays) {
  let result = `Statement for ${data.customer}\n`;
  for (let perf of data.performances) {
    result += ` ${perf.play.name}: ${usd(perf.amount)} (${perf.audience} seats)\n`;
  }
  result += `Amount owed is ${usd(data.totalAmount)}\n`;
  result += `You earned ${data.totalVolumeCredits} credits\n`;
  return result;
}
function htmlStatement (invoice, plays) {
  return renderHtml(createStatementData(invoice, plays));
}
function renderHtml (data) {
  let result = `<h1>Statement for ${data.customer}</h1>\n`;
  result += "<table>\n";
  result += "<tr><th>play</th><th>seats</th><th>cost</th></tr>";
  for (let perf of data.performances) {
    result += `<tr><td>${perf.play.name}</td><td>${perf.audience}</td>`;
    result += `<td>${usd(perf.amount)}</td></tr>\n`;
  }
  result += "</table>\n";
  result += `<p>Amount owed is <em>${usd(data.totalAmount)}</em></p>\n`;
  result += `<p>You earned <em>${data.totalVolumeCredits}</em> credits</p>\n`;
  return result;
}
function usd(aNumber) {
  return new Intl.NumberFormat("en-US",
    { style: "currency", currency: "USD",
      minimumFractionDigits: 2 }).format(aNumber/100);
}

```

createStatementData.js

```

export default function createStatementData(invoice, plays) {
  const result = {};
  result.customer = invoice.customer;
  result.performances = invoice.performances.map(enrichPerformance);
  result.totalAmount = totalAmount(result);
  result.totalVolumeCredits = totalVolumeCredits(result);
  return result;

  function enrichPerformance(aPerformance) {
    const result = Object.assign({}, aPerformance);
    result.play = playFor(result);
    result.amount = amountFor(result);
    result.volumeCredits = volumeCreditsFor(result);
    return result;
  }
}

```

```

function playFor(aPerformance) {
  return plays[aPerformance.playID]
}
function amountFor(aPerformance) {
  let result = 0;
  switch (aPerformance.play.type) {
    case "tragedy":
      result = 40000;
      if (aPerformance.audience > 30) {
        result += 1000 * (aPerformance.audience - 30);
      }
      break;
    case "comedy":
      result = 30000;
      if (aPerformance.audience > 20) {
        result += 10000 + 500 * (aPerformance.audience - 20);
      }
      result += 300 * aPerformance.audience;
      break;
    default:
      throw new Error(`unknown type: ${aPerformance.play.type}`);
  }
  return result;
}
function volumeCreditsFor(aPerformance) {
  let result = 0;
  result += Math.max(aPerformance.audience - 30, 0);
  if ("comedy" === aPerformance.play.type) result += Math.floor(aPerformance.audience / 5);
  return result;
}
function totalAmount(data) {
  return data.performances
    .reduce((total, p) => total + p.amount, 0);
}
function totalVolumeCredits(data) {
  return data.performances
    .reduce((total, p) => total + p.volumeCredits, 0);
}

```

I have more code than I did when I started: 70 lines (not counting `htmlStatement`) as opposed to 44, mostly due to the extra wrapping involved in putting things in functions. If all else is equal, more code is bad—but rarely is all else equal. The extra code breaks up the logic into identifiable parts, separating the calculations of the statements from the layout. This modularity makes it easier for me to understand the parts of the code and how they fit together. Brevity is the soul of wit, but clarity is the soul of evolvable software. Adding this modularity allows to me to support the HTML version of the code without any duplication of the calculations.



When programming, follow the camping rule: Always leave the code base healthier than when you found it.

There are more things I could do to simplify the printing logic, but this will do for the moment. I always have to strike a balance between all the refactorings I could do and adding new features. At the moment, most people under-prioritize refactoring—but there still is a balance. My rule is a variation on the

camping rule: Always leave the code base healthier than when you found it. It will never be perfect, but it should be better.

Reorganizing the Calculations by Type

Now I'll turn my attention to the next feature change: supporting more categories of plays, each with its own charging and volume credits calculations. At the moment, to make changes here I have to go into the calculation functions and edit the conditions in there. The `amountFor` function highlights the central role the type of play has in the choice of calculations—but conditional logic like this tends to decay as further modifications are made unless it's reinforced by more structural elements of the programming language.

There are various ways to introduce structure to make this explicit, but in this case a natural approach is type polymorphism—a prominent feature of classical object-orientation. Classical OO has long been a controversial feature in the JavaScript world, but the ECMAScript 2015 version provides a sound syntax and structure for it. So it makes sense to use it in a right situation—like this one.

My overall plan is to set up an inheritance hierarchy with comedy and tragedy subclasses that contain the calculation logic for those cases. Callers call a polymorphic `amount` function that the language will dispatch to the different calculations for the comedies and tragedies. I'll make a similar structure for the volume credits calculation. To do this, I utilize a couple of refactorings. The core refactoring is *Replace Conditional with Polymorphism* (272), which changes a hunk of conditional code with polymorphism. But before I can do *Replace Conditional with Polymorphism* (272), I need to create an inheritance structure of some kind. I need to create a class to host the `amount` and volume credit functions.

I begin by reviewing the calculation code. (One of the pleasant consequences of the previous refactoring is that I can now ignore the formatting code, so long as I produce the same output data structure. I can further support this by adding tests that probe the intermediate data structure.)

createStatementData.js...

```
export default function createStatementData(invoice, plays) {
  const result = {};
  result.customer = invoice.customer;
  result.performances = invoice.performances.map(enrichPerformance);
  result.totalAmount = totalAmount(result);
  result.totalVolumeCredits = totalVolumeCredits(result);
  return result;

  function enrichPerformance(aPerformance) {
    const result = Object.assign({}, aPerformance);
    result.play = playFor(result);
    result.amount = amountFor(result);
    result.volumeCredits = volumeCreditsFor(result);
    return result;
  }

  function playFor(aPerformance) {
    return plays[aPerformance.playID]
  }

  function amountFor(aPerformance) {
    let result = 0;
    switch (aPerformance.play.type) {
      case "tragedy":
        result = 40000;
        if (aPerformance.audience > 30) {
          result += 1000 * (aPerformance.audience - 30);
        }
        break;
      case "comedy":
        result = 30000;
        if (aPerformance.audience > 20) {
          result += 10000 + 500 * (aPerformance.audience - 20);
        }
        result += 300 * aPerformance.audience;
        break;
      default:
        throw new Error(`unknown type: ${aPerformance.play.type}`);
    }
    return result;
  }

  function volumeCreditsFor(aPerformance) {
    let result = 0;
    result += Math.max(aPerformance.audience - 30, 0);
    if ("comedy" === aPerformance.play.type) result += Math.floor(aPerformance.audience / 5);
    return result;
  }

  function totalAmount(data) {
    return data.performances
      .reduce((total, p) => total + p.amount, 0);
  }
}
```

```
function totalVolumeCredits(data) {
  return data.performances
    .reduce((total, p) => total + p.volumeCredits, 0);
}
```

Creating a Performance Calculator

The `enrichPerformance` function is the key, since it populates the intermediate data structure with the data for each performance. Currently, it calls the conditional functions for amount and volume credits. What I need it to do is call those functions on a host class. Since that class hosts functions for calculating data about performances, I'll call it a performance calculator.

function createStatementData...

```
function enrichPerformance(aPerformance) {
  const calculator = new PerformanceCalculator(aPerformance);
  const result = Object.assign({}, aPerformance);
  result.play = playFor(result);
  result.amount = amountFor(result);
  result.volumeCredits = volumeCreditsFor(result);
  return result;
}
```

top level...

```
class PerformanceCalculator {
  constructor(aPerformance) {
    this.performance = aPerformance;
  }
}
```

So far, this new object isn't doing anything. I want to move behavior into it—and I'd like to start with the simplest thing to move, which is the play record. Strictly, I don't need to do this, as it's not varying polymorphically, but this way I'll keep all the data transforms in one place, and that consistency will make the code clearer.

To make this work, I will use *Change Function Declaration (124)* to pass the performance's play into the calculator.

function createStatementData...

```
function enrichPerformance(aPerformance) {
  const calculator = new PerformanceCalculator(aPerformance, playFor(aPerformance));
  const result = Object.assign({}, aPerformance);
  result.play = calculator.play;
  result.amount = amountFor(result);
  result.volumeCredits = volumeCreditsFor(result);
  return result;
}
```

class PerformanceCalculator...

```
class PerformanceCalculator {
  constructor(aPerformance, aPlay) {
    this.performance = aPerformance;
    this.play = aPlay;
  }
}
```

(I'm not saying compile-test-commit all the time any more, as I suspect you're getting tired of reading it. But I still do it at every opportunity. I do sometimes get tired of doing it—and give mistakes the chance to bite me. Then I learn and get back into the rhythm.)

Moving Functions into the Calculator

The next bit of logic I move is rather more substantial for calculating the amount for a performance. I've moved functions around casually while rearranging nested functions—but this is a deeper change in the context of the function, so I'll step through the *Move Function (198)* refactoring. The first part of this refactoring is to copy the logic over to its new context—the calculator class. Then, I adjust the code to fit into its new home, changing `aPerformance` to `this.performance` and `playFor(aPerformance)` to `this.play`.

class PerformanceCalculator...

```
get amount() {
  let result = 0;
  switch (this.play.type) {
    case "tragedy":
      result = 40000;
      if (this.performance.audience > 30) {
        result += 1000 * (this.performance.audience - 30);
      }
      break;
    case "comedy":
      result = 30000;
      if (this.performance.audience > 20) {
        result += 10000 + 500 * (this.performance.audience - 20);
      }
      result += 300 * this.performance.audience;
      break;
    default:
      throw new Error(`unknown type: ${this.play.type}`);
  }
  return result;
}
```

I can compile at this point to check for any compile-time errors. “Compiling” in my development environment occurs as I execute the code, so what I actually

do is run Babel [babel]. That will be enough to catch any syntax errors in the new function—but little more than that. Even so, that can be a useful step.

Once the new function fits its home, I take the original function and turn it into a delegating function so it calls the new function.

```
function createStatementData...
  function amountFor(aPerformance) {
    return new PerformanceCalculator(aPerformance, playFor(aPerformance)).amount;
  }
```

Now I can compile-test-commit to ensure the code is working properly in its new home. With that done, I use *Inline Function (115)* to call the new function directly (compile-test-commit).

```
function createStatementData...
  function enrichPerformance(aPerformance) {
    const calculator = new PerformanceCalculator(aPerformance, playFor(aPerformance));
    const result = Object.assign({}, aPerformance);
    result.play = calculator.play;
    result.amount = calculator.amount;
    result.volumeCredits = volumeCreditsFor(result);
    return result;
  }
```

I repeat the same process to move the volume credits calculation.

```
function createStatementData...
  function enrichPerformance(aPerformance) {
    const calculator = new PerformanceCalculator(aPerformance, playFor(aPerformance));
    const result = Object.assign({}, aPerformance);
    result.play = calculator.play;
    result.amount = calculator.amount;
    result.volumeCredits = calculator.volumeCredits;
    return result;
  }

  class PerformanceCalculator...
    get volumeCredits() {
      let result = 0;
      result += Math.max(this.performance.audience - 30, 0);
      if ("comedy" === this.play.type) result += Math.floor(this.performance.audience / 5);
      return result;
    }
```

Making the Performance Calculator Polymorphic

Now that I have the logic in a class, it's time to apply the polymorphism. The first step is to use *Replace Type Code with Subclasses (362)* to introduce subclasses instead of the type code. For this, I need to create subclasses of the performance

calculator and use the appropriate subclass in `createPerformanceData`. In order to get the right subclass, I need to replace the constructor call with a function, since JavaScript constructors can't return subclasses. So I use *Replace Constructor with Factory Function* (334).

function createStatementData...

```
function enrichPerformance(aPerformance) {
  const calculator = createPerformanceCalculator(aPerformance, playFor(aPerformance));
  const result = Object.assign({}, aPerformance);
  result.play = calculator.play;
  result.amount = calculator.amount;
  result.volumeCredits = calculator.volumeCredits;
  return result;
}
```

top level...

```
function createPerformanceCalculator(aPerformance, aPlay) {
  return new PerformanceCalculator(aPerformance, aPlay);
}
```

With that now a function, I can create subclasses of the performance calculator and get the creation function to select which one to return.

top level...

```
function createPerformanceCalculator(aPerformance, aPlay) {
  switch(aPlay.type) {
    case "tragedy": return new TragedyCalculator(aPerformance, aPlay);
    case "comedy" : return new ComedyCalculator(aPerformance, aPlay);
    default:
      throw new Error(`unknown type: ${aPlay.type}`);
  }
}

class TragedyCalculator extends PerformanceCalculator {
}
class ComedyCalculator extends PerformanceCalculator {
}
```

This sets up the structure for the polymorphism, so I can now move on to *Replace Conditional with Polymorphism* (272).

I start with the calculation of the amount for tragedies.

class TragedyCalculator...

```
get amount() {
  let result = 40000;
  if (this.performance.audience > 30) {
    result += 1000 * (this.performance.audience - 30);
  }
  return result;
}
```

Just having this method in the subclass is enough to override the superclass conditional. But if you're as paranoid as I am, you might do this:

class PerformanceCalculator...

```
get amount() {
  let result = 0;
  switch (this.play.type) {
    case "tragedy":
      throw 'bad thing';
    case "comedy":
      result = 30000;
      if (this.performance.audience > 20) {
        result += 10000 + 500 * (this.performance.audience - 20);
      }
      result += 300 * this.performance.audience;
      break;
    default:
      throw new Error(`unknown type: ${this.play.type}`);
  }
  return result;
}
```

I could have removed the case for tragedy and let the default branch throw an error. But I like the explicit throw—and it will only be there for a couple more minutes (which is why I threw a string, not a better error object).

After a compile-test-commit of that, I move the comedy case down too.

class ComedyCalculator...

```
get amount() {
  let result = 30000;
  if (this.performance.audience > 20) {
    result += 10000 + 500 * (this.performance.audience - 20);
  }
  result += 300 * this.performance.audience;
  return result;
}
```

I can now remove the superclass amount method, as it should never be called. But it's kinder to my future self to leave a tombstone.

class PerformanceCalculator...

```
get amount() {
  throw new Error('subclass responsibility');
}
```

The next conditional to replace is the volume credits calculation. Looking at the discussion of future categories of plays, I notice that most plays expect to check if audience is above 30, with only some categories introducing a variation. So it makes sense to leave the more common case on the superclass as a default,

and let the variations override it as necessary. So I just push down the case for comedies:

class PerformanceCalculator...

```
get volumeCredits() {
  return Math.max(this.performance.audience - 30, 0);
}
```

class ComedyCalculator...

```
get volumeCredits() {
  return super.volumeCredits + Math.floor(this.performance.audience / 5);
}
```

Status: Creating the Data with the Polymorphic Calculator

Time to reflect on what introducing the polymorphic calculator did to the code.

createStatementData.js

```
export default function createStatementData(invoice, plays) {
  const result = {};
  result.customer = invoice.customer;
  result.performances = invoice.performances.map(enrichPerformance);
  result.totalAmount = totalAmount(result);
  result.totalVolumeCredits = totalVolumeCredits(result);
  return result;

  function enrichPerformance(aPerformance) {
    const calculator = createPerformanceCalculator(aPerformance, playFor(aPerformance));
    const result = Object.assign({}, aPerformance);
    result.play = calculator.play;
    result.amount = calculator.amount;
    result.volumeCredits = calculator.volumeCredits;
    return result;
  }

  function playFor(aPerformance) {
    return plays[aPerformance.playID]
  }

  function totalAmount(data) {
    return data.performances
      .reduce((total, p) => total + p.amount, 0);
  }

  function totalVolumeCredits(data) {
    return data.performances
      .reduce((total, p) => total + p.volumeCredits, 0);
  }
}
```

```

function createPerformanceCalculator(aPerformance, aPlay) {
  switch(aPlay.type) {
    case "tragedy": return new TragedyCalculator(aPerformance, aPlay);
    case "comedy" : return new ComedyCalculator(aPerformance, aPlay);
    default:
      throw new Error(`unknown type: ${aPlay.type}`);
  }
}

class PerformanceCalculator {
  constructor(aPerformance, aPlay) {
    this.performance = aPerformance;
    this.play = aPlay;
  }
  get amount() {
    throw new Error('subclass responsibility');
  }
  get volumeCredits() {
    return Math.max(this.performance.audience - 30, 0);
  }
}

class TragedyCalculator extends PerformanceCalculator {
  get amount() {
    let result = 40000;
    if (this.performance.audience > 30) {
      result += 1000 * (this.performance.audience - 30);
    }
    return result;
  }
}

class ComedyCalculator extends PerformanceCalculator {
  get amount() {
    let result = 30000;
    if (this.performance.audience > 20) {
      result += 10000 + 500 * (this.performance.audience - 20);
    }
    result += 300 * this.performance.audience;
    return result;
  }
  get volumeCredits() {
    return super.volumeCredits + Math.floor(this.performance.audience / 5);
  }
}

```

Again, the code has increased in size as I've introduced structure. The benefit here is that the calculations for each kind of play are grouped together. If most of the changes will be to this code, it will be helpful to have it clearly separated like this. Adding a new kind of play requires writing a new subclass and adding it to the creation function.

The example gives some insight as to when using subclasses like this is useful. Here, I've moved the conditional lookup from two functions (`amountFor` and `volumeCreditsFor`) to a single constructor function `createPerformanceCalculator`. The more

functions there are that depend on the same type of polymorphism, the more useful this approach becomes.

An alternative to what I've done here would be to have `createPerformanceData` return the calculator itself, instead of the calculator populating the intermediate data structure. One of the nice features of JavaScript's class system is that with it, using getters looks like regular data access. My choice on whether to return the instance or calculate separate output data depends on who is using the downstream data structure. In this case, I preferred to show how to use the intermediate data structure to hide the decision to use a polymorphic calculator.

Final Thoughts

This is a simple example, but I hope it will give you a feeling for what refactoring is like. I've used several refactorings, including *Extract Function* (106), *Inline Variable* (123), *Move Function* (198), and *Replace Conditional with Polymorphism* (272).

There were three major stages to this refactoring episode: decomposing the original function into a set of nested functions, using *Split Phase* (154) to separate the calculation and printing code, and finally introducing a polymorphic calculator for the calculation logic. Each of these added structure to the code, enabling me to better communicate what the code was doing.

As is often the case with refactoring, the early stages were mostly driven by trying to understand what was going on. A common sequence is: Read the code, gain some insight, and use refactoring to move that insight from your head back into the code. The clearer code then makes it easier to understand it, leading to deeper insights and a beneficial positive feedback loop. There are still some improvements I could make, but I feel I've done enough to pass my test of leaving the code significantly better than how I found it.

I'm talking about improving the code—but programmers love to argue about what good code looks like. I know some people object to my preference for small, well-named functions. If we con-

sider this to be a matter of aesthetics, where nothing is either good or bad but thinking makes it so, we lack any guide but personal taste. I believe, however, that we can go beyond taste and say that the true test of good code is how easy it is to change it. Code should be obvious: When someone needs to make a change, they should be able to find the code to be changed easily and to make the change quickly without introducing any errors. A healthy code base maximizes our productivity, allowing us to build more features for our users both faster and more cheaply. To keep code healthy, pay attention to what is getting between the programming team and that ideal, then refactor to get closer to the ideal.

The true test of good code is how easy it is to change it.



But the most important thing to learn from this example is the rhythm of refactoring. Whenever I've shown people how I refactor, they are surprised by how small my steps are, each step leaving the code in a working state that compiles and passes its tests. I was just as surprised myself when Kent Beck showed me how to do this in a hotel room in Detroit two decades ago. The key to effective refactoring is recognizing that you go faster when you take tiny steps, the code is never broken, and you can compose those small steps into substantial changes. Remember that—and the rest is silence.

Chapter 2

Principles in Refactoring

The example in the previous chapter should have given you a decent feel of what refactoring is. Now you have that, it's a good time to step back and talk about some of the broader principles in refactoring.

Defining Refactoring

Like many terms in software development, “refactoring” is often used very loosely by practitioners. I use the term more precisely, and find it useful to use it in that more precise form. (These definitions are the same as those I gave in the first edition of this book.) The term “refactoring” can be used either as a noun or a verb. The noun’s definition is:

Refactoring (noun): a change made to the internal structure of software to make it easier to understand and cheaper to modify without changing its observable behavior.

This definition corresponds to the named refactorings I’ve mentioned in the earlier examples, such as *Extract Function* (106) and *Replace Conditional with Polymorphism* (272).

The verb’s definition is:

Refactoring (verb): to restructure software by applying a series of refactorings without changing its observable behavior.

So I might spend a couple of hours refactoring, during which I would apply a few dozen individual refactorings.

Over the years, many people in the industry have taken to use “refactoring” to mean any kind of code cleanup—but the definitions above point to a particular approach to cleaning up code. Refactoring is all about applying small behavior-preserving steps and making a big change by stringing together a sequence of these behavior-preserving steps. Each individual refactoring is either pretty small

itself or a combination of small steps. As a result, when I'm refactoring, my code doesn't spend much time in a broken state, allowing me to stop at any moment even if I haven't finished.



If someone says their code was broken for a couple of days while they are refactoring, you can be pretty sure they were not refactoring.

I use “restructuring” as a general term to mean any kind of reorganizing or cleaning up of a code base, and see refactoring as a particular kind of restructuring. Refactoring may seem inefficient to people who first come across it and watch me making lots of tiny steps, when a single bigger step would do. But the tiny steps allow me to go faster because

they compose so well—and, crucially, because I don't spend any time debugging.

In my definitions, I use the phrase “observable behavior.” This is a deliberately loose term, indicating that the code should, overall, do just the same things it did before I started. It doesn't mean it will work exactly the same—for example, *Extract Function* (106) will alter the call stack, so performance characteristics might change—but nothing should change that the user should care about. In particular, interfaces to modules often change due to such refactorings as *Change Function Declaration* (124) and *Move Function* (198). Any bugs that I notice during refactoring should still be present after refactoring (though I can fix latent bugs that nobody has observed yet).

Refactoring is very similar to performance optimization, as both involve carrying out code manipulations that don't change the overall functionality of the program. The difference is the purpose: Refactoring is always done to make the code “easier to understand and cheaper to modify.” This might speed things up or slow things down. With performance optimization, I only care about speeding up the program, and am prepared to end up with code that is harder to work with if I really need that improved performance.

The Two Hats

Kent Beck came up with a metaphor of the two hats. When I use refactoring to develop software, I divide my time between two distinct activities: adding functionality and refactoring. When I add functionality, I shouldn't be changing existing code; I'm just adding new capabilities. I measure my progress by adding tests and getting the tests to work. When I refactor, I make a point of not adding functionality; I only restructure the code. I don't add any tests (unless I find a case I missed earlier); I only change tests when I have to accommodate a change in an interface.

As I develop software, I find myself swapping hats frequently. I start by trying to add a new capability, then I realize this would be much easier if the code were

structured differently. So I swap hats and refactor for a while. Once the code is better structured, I swap hats back and add the new capability. Once I get the new capability working, I realize I coded it in a way that's awkward to understand, so I swap hats again and refactor. All this might take only ten minutes, but during this time I'm always aware of which hat I'm wearing and the subtle difference that makes to how I program.

Why Should We Refactor?

I don't want to claim refactoring is the cure for all software ills. It is no "silver bullet." Yet it is a valuable tool—a pair of silver pliers that helps you keep a good grip on your code. Refactoring is a tool that can—and should—be used for several purposes.

Refactoring Improves the Design of Software

Without refactoring, the internal design—the architecture—of software tends to decay. As people change code to achieve short-term goals, often without a full comprehension of the architecture, the code loses its structure. It becomes harder for me to see the design by reading the code. Loss of the structure of code has a cumulative effect. The harder it is to see the design in the code, the harder it is for me to preserve it, and the more rapidly it decays. Regular refactoring helps keep the code in shape.

Poorly designed code usually takes more code to do the same things, often because the code quite literally does the same thing in several places. Thus an important aspect of improving design is to eliminate duplicated code. It's not that reducing the amount of code will make the system run any faster—the effect on the footprint of the programs rarely is significant. Reducing the amount of code does, however, make a big difference in modification of the code. The more code there is, the harder it is to modify correctly. There's more code for me to understand. I change this bit of code here, but the system doesn't do what I expect because I didn't change that bit over there that does much the same thing in a slightly different context. By eliminating duplication, I ensure that the code says everything once and only once, which is the essence of good design.

Refactoring Makes Software Easier to Understand

Programming is in many ways a conversation with a computer. I write code that tells the computer what to do, and it responds by doing exactly what I tell it. In time, I close the gap between what I want it to do and what I tell it to do. Programming is all about saying exactly what I want. But there are likely to be other users of my source code. In a few months, a human will try to read my

code to make some changes. That user, who we often forget, is actually the most important. Who cares if the computer takes a few more cycles to compile something? Yet it does matter if it takes a programmer a week to make a change that would have taken only an hour with proper understanding of my code.

The trouble is that when I'm trying to get the program to work, I'm not thinking about that future developer. It takes a change of rhythm to make the code easier to understand. Refactoring helps me make my code more readable. Before refactoring, I have code that works but is not ideally structured. A little time spent on refactoring can make the code better communicate its purpose—say more clearly what I want.

I'm not necessarily being altruistic about this. Often, this future developer is myself. This makes refactoring even more important. I'm a very lazy programmer. One of my forms of laziness is that I never remember things about the code I write. Indeed, I deliberately try not remember anything I can look up, because I'm afraid my brain will get full. I make a point of trying to put everything I should remember into the code so I don't have to remember it. That way I'm less worried about Maudite [maudite] killing off my brain cells.

Refactoring Helps Me Find Bugs

Help in understanding the code also means help in spotting bugs. I admit I'm not terribly good at finding bugs. Some people can read a lump of code and see bugs; I cannot. However, I find that if I refactor code, I work deeply on understanding what the code does, and I put that new understanding right back into the code. By clarifying the structure of the program, I clarify certain assumptions I've made—to a point where even I can't avoid spotting the bugs.

It reminds me of a statement Kent Beck often makes about himself: "I'm not a great programmer; I'm just a good programmer with great habits." Refactoring helps me be much more effective at writing robust code.

Refactoring Helps Me Program Faster

In the end, all the earlier points come down to this: Refactoring helps me develop code more quickly.

This sounds counterintuitive. When I talk about refactoring, people can easily see that it improves quality. Better internal design, readability, reducing bugs—all these improve quality. But doesn't the time I spend on refactoring reduce the speed of development?

When I talk to software developers who have been working on a system for a while, I often hear that they were able to make progress rapidly at first, but now it takes much longer to add new features. Every new feature requires more and more time to understand how to fit it into the existing code base, and once it's added, bugs often crop up that take even longer to fix. The code base starts looking like a series of patches covering patches, and it takes an exercise in

archaeology to figure out how things work. This burden slows down adding new features—to the point that developers wish they could start again from a blank slate.

I can visualize this state of affairs with the following pseudograph:



But some teams report a different experience. They find they can add new features *faster* because they can leverage the existing things by quickly building on what's already there.



The difference between these two is the internal quality of the software. Software with a good internal design allows me to easily find how and where I need to make changes to add a new feature. Good modularity allows me to only have to understand a small subset of the code base to make a change. If the code is clear, I'm less likely to introduce a bug, and if I do, the debugging effort is much easier.

Done well, my code base turns into a platform for building new features for its domain.

I refer to this effect as the Design Stamina Hypothesis [mf-dsh]: By putting our effort into a good internal design, we increase the stamina of the software effort, allowing us to go faster for longer. I can't prove that this is the case, which is why I refer to it as a hypothesis. But it explains my experience, together with the experience of hundreds of great programmers that I've got to know over my career.

Twenty years ago, the conventional wisdom was that to get this kind of good design, it had to be completed before starting to program—because once we wrote the code, we could only face decay. Refactoring changes this picture. We now know we can improve the design of existing code—so we can form and improve a design over time, even as the needs of the program change. Since it is very difficult to do a good design up front, refactoring becomes vital to achieving that virtuous path of rapid functionality.

When Should We Refactor?

Refactoring is something I do every hour I program. I have noticed a number of ways it fits into my workflow.

The Rule of Three

Here's a guideline Don Roberts gave me: The first time you do something, you just do it. The second time you do something similar, you wince at the duplication, but you do the duplicate thing anyway. The third time you do something similar, you refactor.

Or for those who like baseball: **Three strikes, then you refactor.**

Preparatory Refactoring—Making It Easier to Add a Feature

The best time to refactor is just before I need to add a new feature to the code base. As I do this, I look at the existing code and, often, see that if it were structured a little differently, my work would be much easier. Perhaps there's function that does almost all that I need, but has some literal values that conflict with my needs. Without refactoring I might copy the function and change those values. But that leads to duplicated code—if I need to change it in the future, I'll have to change both spots (and, worse, find them). And copy-paste won't help me if I need to make a similar variation for a new feature in the future. So with my refactoring hat on, I use *Parameterize Function* (310). Once I've done that, all I have to do is call the function with the parameters I need.

"It's like I want to go 100 miles east but instead of just traipsing through the woods, I'm going to drive 20 miles north to the highway and then I'm going to go 100 miles east at three times the speed I could have if I just went straight there. When people are pushing you to just go straight there, sometimes you need to say, 'Wait, I need to check the map and find the quickest route.' The preparatory refactoring does that for me."

— Jessica Kerr,

<https://martinfowler.com/articles/preparatory-refactoring-example.html>

The same happens when fixing a bug. Once I've found the cause of the problem, I see that it would be much easier to fix should I unify the three bits of copied code causing the error into one. Or perhaps separating some update logic from queries will make it easier to avoid the tangling that's causing the error. By refactoring to improve the situation, I also increase the chances that the bug will stay fixed, and reduce the chances that others will appear in the same crevices of the code.

Comprehension Refactoring: Making Code Easier to Understand

Before I can change some code, I need to understand what it does. This code may have been written by me or by someone else. Whenever I have to think to understand what the code is doing, I ask myself if I can refactor the code to make that understanding more immediately apparent. I may be looking at some conditional logic that's structured awkwardly. I may have wanted to use some existing functions but spent several minutes figuring out what they did because they were named badly.

At that point I have some understanding in my head, but my head isn't a very good record of such details. As Ward Cunningham puts it, by refactoring I move the understanding from my head into the code itself. I then test that understanding by running the software to see if it still works. If I move my understanding into the code, it will be preserved longer and be visible to my colleagues.

That doesn't just help me in the future—it often helps me right now. Early on, I do comprehension refactoring on little details. I rename a couple variables now that I understand what they are, or I chop a long function into smaller parts. Then, as the code gets clearer, I find I can see things about the design that I could not see before. Had I not changed the code, I probably never would have seen these things, because I'm just not clever enough to visualize all these changes in my head. Ralph Johnson describes these early refactorings as wiping the dirt off a window so you can see beyond. When I'm studying code, refactoring leads me to higher levels of understanding that I would otherwise miss. Those who dismiss comprehension refactoring as useless fiddling with the code don't realize that by foregoing it they never see the opportunities hidden behind the confusion.

Litter-Pickup Refactoring

A variation of comprehension refactoring is when I understand what the code is doing, but realize that it's doing it badly. The logic is unnecessarily convoluted, or I see functions that are nearly identical and can be replaced by a single parameterized function. There's a bit of a tradeoff here. I don't want to spend a lot of time distracted from the task I'm currently doing, but I also don't want to leave the trash lying around and getting in the way of future changes. If it's easy to change, I'll do it right away. If it's a bit more effort to fix, I might make a note of it and fix it when I'm done with my immediate task.

Sometimes, of course, it's going to take a few hours to fix, and I have more urgent things to do. Even then, however, it's usually worthwhile to make it a little bit better. As the old camping adage says, always leave the camp site cleaner than when you found it. If I make it a little better each time I pass through the code, over time it will get fixed. The nice thing about refactoring is that I don't break the code with each small step—so, sometimes, it takes months to complete the job but the code is never broken even when I'm part way through it.

Planned and Opportunistic Refactoring

The examples above—preparatory, comprehension, litter-pickup refactoring—are all opportunistic. I don't set aside time at the beginning to spend on refactoring—instead, I do refactoring as part of adding a feature or fixing a bug. It's part of my natural flow of programming. Whether I'm adding a feature or fixing a bug, refactoring helps me do the immediate task and also sets me up to make future work easier. This is an important point that's frequently missed. Refactoring isn't an activity that's separated from programming—any more than you set aside time to write if statements. I don't put time on my plans to do refactoring; most refactoring happens while I'm doing other things.



You have to refactor when you run into ugly code—but excellent code needs plenty of refactoring too.

It's also a common error to see refactoring as something people do to fix past mistakes or clean up ugly code. Certainly you have to refactor when you run into ugly code, but excellent code needs plenty of refactoring too. Whenever I write code, I'm making tradeoffs—how much do I need to parameterize, where

to draw the lines between functions? The tradeoffs I made correctly for yesterday's feature set may no longer be the right ones for the new features I'm adding today. The advantage is that clean code is easier to refactor when I need to change those tradeoffs to reflect the new reality.

*“for each desired change, make the change easy (warning: this may be hard),
then make the easy change”*
— Kent Beck,

<https://twitter.com/kentbeck/status/250733358307500032>

For a long time, people thought of writing software as a process of accretion: To add new features, we should be mostly adding new code. But good developers know that, often, the fastest way to add a new feature is to change the code to make it easy to add. Software should thus be never thought of as “done.” As new capabilities are needed, the software changes to reflect that. Those changes can often be greater in the existing code than in the new code.

All this doesn’t mean that planned refactoring is always wrong. If a team has neglected refactoring, it often needs dedicated time to get their code base into a better state for new features, and a week spent refactoring now can repay itself over the next couple of months. Sometimes, even with regular refactoring I’ll see a problem area grow to the point when it needs some concerted effort to fix. But such planned refactoring episodes should be rare. Most refactoring effort should be the unremarkable, opportunistic kind.

One bit of advice I’ve heard is to separate refactoring work and new feature additions into different version-control commits. The big advantage of this is that they can be reviewed and approved independently. I’m not convinced of this, however. Too often, the refactorings are closely interwoven with adding new features, and it’s not worth the time to separate them out. This can also remove the context for the refactoring, making the refactoring commits hard to justify. Each team should experiment to find what works for them; just remember that separating refactoring commits is not a self-evident principle—it’s only worthwhile if it makes life easier.

Long-Term Refactoring

Most refactoring can be completed within a few minutes—hours at most. But there are some larger refactoring efforts that can take a team weeks to complete. Perhaps they need to replace an existing library with a new one. Or pull some section of code out into a component that they can share with another team. Or fix some nasty mess of dependencies that they had allowed to build up.

Even in such cases, I’m reluctant to have a team do dedicated refactoring. Often, a useful strategy is to agree to gradually work on the problem over the course of the next few weeks. Whenever anyone goes near any code that’s in the refactoring zone, they move it a little way in the direction they want to improve. This takes advantage of the fact that refactoring doesn’t break the code—each small change leaves everything in a still-working state. To change from one library to another, start by introducing a new abstraction that can act as an interface to either library. Once the calling code uses this abstraction, it’s much easier

to switch one library for another. (This tactic is called Branch By Abstraction [mf-bba].)

Refactoring in a Code Review

Some organizations do regular code reviews; those that don't would do better if they did. Code reviews help spread knowledge through a development team. Reviews help more experienced developers pass knowledge to those less experienced. They help more people understand more aspects of a large software system. They are also very important in writing clear code. My code may look clear to me but not to my team. That's inevitable—it's hard for people to put themselves in the shoes of someone unfamiliar with whatever they are working on. Reviews also give the opportunity for more people to suggest useful ideas. I can only think of so many good ideas in a week. Having other people contribute makes my life easier, so I always look for reviews.

I've found that refactoring helps me review someone else's code. Before I started using refactoring, I could read the code, understand it to some degree, and make suggestions. Now, when I come up with ideas, I consider whether they can be easily implemented then and there with refactoring. If so, I refactor. When I do it a few times, I can see more clearly what the code looks like with the suggestions in place. I don't have to imagine what it would be like—I can see it. As a result, I can come up with a second level of ideas that I would never have realized had I not refactored.

Refactoring also helps get more concrete results from the code review. Not only are there suggestions; many suggestions are implemented there and then. You end up with much more of a sense of accomplishment from the exercise.

How I'd embed refactoring into a code review depends on the nature of the review. The common pull request model, where a reviewer looks at code without the original author, doesn't work too well. It's better to have the original author of the code present because the author can provide context on the code and fully appreciate the reviewers' intentions for their changes. I've had my best experiences with this by sitting one-on-one with the original author, going through the code and refactoring as we go. The logical conclusion of this style is *pair programming*: continuous code review embedded within the process of programming.

What Do I Tell My Manager?

One of the most common questions I've been asked is, "How to tell a manager about refactoring?" I've certainly seen places where refactoring has become a dirty word—with managers (and customers) believing that refactoring is either correcting errors made earlier, or work that doesn't yield valuable features. This is exacerbated by teams scheduling weeks of pure refactoring—especially if what they are

really doing is not refactoring but less careful restructuring that causes breakages in the code base.

To a manager who is genuinely savvy about technology and understands the design stamina hypothesis, refactoring isn't hard to justify. Such managers should be encouraging refactoring on a regular basis and be looking for signs that indicate a team isn't doing enough. While it does happen that teams do too much refactoring, it's much rarer than teams not doing enough.

Of course, many managers and customer don't have the technical awareness to know how code base health impacts productivity. In these cases I give my more controversial advice: *Don't tell!*

Subversive? I don't think so. Software developers are professionals. Our job is to build effective software as rapidly as we can. My experience is that refactoring is a big aid to building software quickly. If I need to add a new function and the design does not suit the change, I find it's quicker to refactor first and then add the function. If I need to fix a bug, I need to understand how the software works—and I find refactoring is the fastest way to do this. A schedule-driven manager wants me to do things the fastest way I can; how I do it is my responsibility. I'm being paid for my expertise in programming new capabilities fast, and the fastest way is by refactoring—therefore I refactor.

When Should I Not Refactor?

It may sound like I always recommend refactoring—but there are cases when it's not worthwhile.

If I run across code that is a mess, but I don't need to modify it, then I don't need to refactor it. Some ugly code that I can treat as an API may remain ugly. It's only when I need to understand how it works that refactoring gives me any benefit.

Another case is when it's easier to rewrite it than to refactor it. This is a tricky decision. Often, I can't tell how easy it is to refactor some code unless I spend some time trying and thus get a sense of how difficult it is. The decision to refactor or rewrite requires good judgment and experience, and I can't really boil it down into a piece of simple advice.

Problems with Refactoring

Whenever anyone advocates for some technique, tool, or architecture, I always look for problems. Few things in life are all sunshine and clear skies. You need to understand the tradeoffs to decide when and where to apply something. I do think refactoring is a valuable technique—one that should be used more by most teams. But there are problems associated with it, and it's important to understand how they manifest themselves and how we can react to them.

Slowing Down New Features

If you read the previous section, you should already know my response. Although many people see time spent refactoring as slowing down the development of new features, the whole purpose of refactoring is to speed things up. But while this is true, it's also true that the perception of refactoring as slowing things down is still common—and perhaps the biggest barrier to people doing enough refactoring.



The whole purpose of refactoring is to make us program faster, producing more value with less effort.

There is a genuine tradeoff here. I do run into situations where I see a (large-scale) refactoring that really needs to be done, but the new feature I want to add is so small that I prefer to add it and leave the larger refactoring alone. That's a judgment call—part of my professional skills as a programmer. I can't easily

describe, let alone quantify, how I make that tradeoff.

I'm very conscious that preparatory refactoring often makes a change easier, so I certainly will do it if I see that it makes my new feature easier to implement. I'm also more inclined to refactor if this is a problem I've seen before—sometimes it takes me a couple of times seeing some particular ugliness before I decide to refactor it away. Conversely, I'm more likely to not refactor if it's part of the code I rarely touch and the cost of the inconvenience isn't something I feel very often. Sometimes, I delay a refactoring because I'm not sure what improvement to do, although at other times I'll try something as an experiment to see if it makes things better.

Still, the evidence I hear from my colleagues in the industry is that too little refactoring is far more prevalent than too much. In other words, most people should try to refactor more often. You may have trouble telling the difference in productivity between a healthy and a sickly code base because you haven't had enough experience of a healthy code base—of the power that comes from easily combining existing parts into new configurations to quickly enable complicated new features.

Although it's often managers that are criticized for the counter-productive habit of squelching refactoring in the name of speed, I've often seen developers do it to themselves. Sometimes, they think they shouldn't be refactoring even though their leadership is actually in favor. If you're a tech lead in a team, it's important to show team members that you value improving the health of a code base. That judgment I mentioned earlier on whether to refactor or not is something that takes years of experience to build up. Those with less experience in refactoring need lots of mentoring to accelerate them through the process.

But I think the most dangerous way that people get trapped is when they try to justify refactoring in terms of “clean code,” “good engineering practice,” or similar moral reasons. The point of refactoring isn't to show how sparkly a code

base is—it is purely economic. We refactor because it makes us faster—faster to add features, faster to fix bugs. It’s important to keep that in front of your mind and in front of communication with others. The economic benefits of refactoring should always be the driving factor, and the more that is understood by developers, managers, and customers, the more of the “good design” curve we’ll see.

Code Ownership

Many refactorings involve making changes that affect not just the internals of a module but its relationships with other parts of a system. If I want to rename a function, and I can find all the callers to a function, I simply apply *Change Function Declaration* (124) and change the declaration and the callers in one change. But sometimes this simple refactoring isn’t possible. Perhaps the calling code is owned by a different team and I don’t have write access to their repository. Perhaps the function is a declared API used by my customers—so I can’t even tell if it’s being used, let alone by who and how much. Such functions are part of a **published interface**—an interface that is used by clients independent of those who declare the interface.

Code ownership boundaries get in the way of refactoring because I cannot make the kinds of changes I want without breaking my clients. This doesn’t prevent refactoring—I can still do a great deal—but it does impose limitations. When renaming a function, I need to use *Rename Function* (124) and to retain the old declaration as a pass-through to the new one. This complicates the interface—but it is the price I must pay to avoid breaking my clients. I may be able to mark the old interface as deprecated and, in time, retire it, but sometimes I have to retain that interface forever.

Due to these complexities, I recommend against fine-grained strong code ownership. Some organizations like any piece of code to have a single programmer as an owner, and only allow that programmer to change it. I’ve seen a team of three people operate in such a way that each one published interfaces to the other two. This led to all sorts of gyrations to maintain interfaces when it would have been much easier to go into the code base and make the edits. My preference is to allow team ownership of code—so that anyone in the same team can modify the team’s code, even if originally written by someone else. Programmers may have individual responsibility for areas of a system, but that should imply that they monitor changes to their area of responsibility, not block them by default.

Such a more permissive ownership scheme can even exist across teams. Some teams encourage an open-source-like model where people from other teams can change a branch of their code and send the commit in to be approved. This allows one team to change the clients of their functions—they can delete the old declarations once their commits to their clients have been accepted. This can often be a good compromise between strong code ownership and chaotic changes in large systems.

Branches

As I write this, a common approach in teams is for each team member to work on a branch of the code base using a version control system, and do considerable work on that branch before integrating with a mainline (often called master or trunk) shared across the team. Often, this involves building a whole feature on a branch, not integrating into the mainline until the feature is ready to be released into production. Fans of this approach claim that it keeps the mainline clear of any in-process code, provides a clear version history of feature additions, and allows features to be reverted easily should they cause problems.

There are downsides to feature branches like this. The longer I work on an isolated branch, the harder the job of integrating my work with mainline is going to be when I'm done. Most people reduce this pain by frequently merging or rebasing from mainline to my branch. But this doesn't really solve the problem when several people are working on individual feature branches. I distinguish between merging and integration. If I merge mainline into my code, this is a one-way movement—my branch changes but the mainline doesn't. I use "integrate" to mean a two-way process that pulls changes from mainline into my branch and then pushes the result back into mainline, changing both. If Rachel is working on her branch I don't see her changes until she integrates with mainline; at that point, I have to merge her changes into my feature branch, which may mean considerable work. The hard part of this work is dealing with semantic changes. Modern version control systems can do wonders with merging complex changes to the program text, but they are blind to the semantics of the code. If I've changed the name of a function, my version control tool may easily integrate my changes with Rachel's. But if, in her branch, she added a call to a function that I've renamed in mine, the code will fail.

The problem of complicated merges gets exponentially worse as the length of feature branches increases. Integrating branches that are four weeks old is more than twice as hard as those that are a couple of weeks old. Many people, therefore, argue for keeping feature branches short—perhaps just a couple of days. Others, such as me, want them even shorter than that. This is an approach called Continuous Integration (CI), also known as Trunk-Based Development. With CI, each team member integrates with mainline at least once per day. This prevents any branches diverting too far from each other and thus greatly reduces the complexity of merges. CI doesn't come for free: It means you use practices to ensure the mainline is healthy, learn to break large features into smaller chunks, and use feature toggles (aka feature flags) to switch off any in-process features that can't be broken down.

Fans of CI like it partly because it reduces the complexity of merges, but the dominant reason to favor CI is that it's far more compatible with refactoring. Refactorings often involve making lots of little changes all over the code base—which are particularly prone to semantic merge conflicts (such as renaming a widely used function). Many of us have seen feature-branching teams that find

refactorings so exacerbate merge problems that they stop refactoring. CI and refactoring work well together, which is why Kent Beck combined them in Extreme Programming.

I'm not saying that you should never use feature branches. If they are sufficiently short, their problems are much reduced. (Indeed, users of CI usually also use branches, but integrate them with mainline each day.) Feature branches may be the right technique for open source projects where you have infrequent commits from programmers who you don't know well (and thus don't trust). But in a full-time development team, the cost that feature branches impose on refactoring is excessive. Even if you don't go to full CI, I certainly urge you to integrate as frequently as possible. You should also consider the objective evidence [Forsgren et al.] that teams that use CI are more effective in software delivery.

Testing

One of the key characteristics of refactoring is that it doesn't change the observable behavior of the program. If I follow the refactorings carefully, I shouldn't break anything—but what if I make a mistake? (Or, knowing me, *s/if/when.*) Mistakes happen, but they aren't a problem provided I catch them quickly. Since each refactoring is a small change, if I break anything, I only have a small change to look at to find the fault—and if I still can't spot it, I can revert my version control to the last working version.

The key here is being able to catch an error quickly. To do this, realistically, I need to be able to run a comprehensive test suite on the code—and run it quickly, so that I'm not deterred from running it frequently. This means that in most cases, if I want to refactor, I need to have self-testing code [mf-stc].

To some readers, self-testing code sounds like a requirement so steep as to be unrealizable. But over the last couple of decades, I've seen many teams build software this way. It takes attention and dedication to testing, but the benefits make it really worthwhile. Self-testing code not only enables refactoring—it also makes it much safer to add new features, since I can quickly find and kill any bugs I introduce. The key point here is that when a test fails, I can look at the change I've made between when the tests were last running correctly and the current code. With frequent test runs, that will be only a few lines of code. By knowing it was those few lines that caused the failure, I can much more easily find the bug.

This also answers those who are concerned that refactoring carries too much risk of introducing bugs. Without self-testing code, that's a reasonable worry—which is why I put so much emphasis on having solid tests.

There is another way to deal with the testing problem. If I use an environment that has good automated refactorings, I can trust those refactorings even without running tests. I can then refactor, providing I only use those refactorings that are safely automated. This removes a lot of nice refactorings from my menu, but still

leaves me enough to deliver some useful benefits. I'd still rather have self-testing code, but it's an option that is useful to have in the toolkit.

This also inspires a style of refactoring that only uses a limited set of refactorings that can be proven safe. Such refactorings require carefully following the steps, and are language-specific. But teams using them have found they can do useful refactoring on large code bases with poor test coverage. I don't focus on that in this book, as it's a newer, less described and understood technique that involves detailed, language-specific activity. (It is, however, something I hope talk about more on my web site in the future. For a taste of it, see Jay Bazuzi's description [Bazuzi] of a safer way to do *Extract Method* (106) in C++.)

Self-testing code is, unsurprisingly, closely associated with Continuous Integration—it is the mechanism that we use to catch semantic integration conflicts. Such testing practices are another component of Extreme Programming and a key part of Continuous Delivery.

Legacy Code

Most people would regard a big legacy as a Good Thing—but that's one of the cases where programmers' view is different. Legacy code is often complex, frequently comes with poor tests, and, above all, is written by Someone Else (shudder).

Refactoring can be a fantastic tool to help understand a legacy system. Functions with misleading names can be renamed so they make sense, awkward programming constructs smoothed out, and the program turned from a rough rock to a polished gem. But the dragon guarding this happy tale is the common lack of tests. If you have a big legacy system with no tests, you can't safely refactor it into clarity.

The obvious answer to this problem is that you add tests. But while this sounds a simple, if laborious, procedure, it's often much more tricky in practice. Usually, a system is only easy to put under test if it was designed with testing in mind—in which case it would have the tests and I wouldn't be worrying about it.

There's no simple route to dealing with this. The best advice I can give is to get a copy of *Working Effectively with Legacy Code* [Feathers] and follow its guidance. Don't be worried by the age of the book—its advice is just as true more than a decade later. To summarize crudely, it advises you to get the system under test by finding seams in the program where you can insert tests. Creating these seams involves refactoring—which is much more dangerous since it's done without tests, but is a necessary risk to make progress. This is a situation where safe, automated refactorings can be a godsend. If all this sounds difficult, that's because it is. Sadly, there's no shortcut to getting out of a hole this deep—which is why I'm such a strong proponent of writing self-testing code from the start.

Even when I do have tests, I don't advocate trying to refactor a complicated legacy mess into beautiful code all at once. What I prefer to do is tackle it in relevant pieces. Each time I pass through a section of the code, I try to make it a little bit better—again, like leaving a camp site cleaner than when I found it. If this is a large system, I'll do more refactoring in areas I visit frequently—which is the right thing to do because, if I need to visit code frequently, I'll get a bigger payoff by making it easier to understand.

Databases

When I wrote the first edition of this book, I said that refactoring databases was a problem area. But, within a year of the book's publication, that was no longer the case. My colleague Pramod Sadalage developed an approach to evolutionary database design [mf-evodb] and database refactoring [Ambler & Sadalage] that is now widely used. The essence of the technique is to combine the structural changes to a database's schema and access code with data migration scripts that can easily compose to handle large changes.

Consider a simple example of renaming a field (column). As in *Change Function Declaration* (124), I need to find the original declaration of the structure and all the callers of this structure and change them in a single change. The complication, however, is that I also have to transform any data that uses the old field to use the new one. I write a small hunk of code that carries out this transform and store it in version control, together with the code that changes any declared structure and access routines. Then, whenever I need to migrate between two versions of the database, I run all the migration scripts that exist between my current copy of the database and my desired version.

As with regular refactoring, the key here is that each individual change is small yet captures a complete change, so the system still runs after applying the migration. Keeping them small means they are easy to write, but I can string many of them into a sequence that can make a significant change to the database's structure and the data stored in it.

One difference from regular refactorings is that database changes often are best separated over multiple releases to production. This makes it easy to reverse any change that causes a problem in production. So, when renaming a field, my first commit would add the new database field but not use it. I may then set up the updates so they update both old and new fields at once. I can then gradually move the readers over to the new field. Only once they have all moved to the new field, and I've given a little time for any bugs to show themselves, would I remove the now-unused old field. This approach to database changes is an example of a general approach of parallel change [mf-pc] (also called expand-contract).

Refactoring, Architecture, and Yagni

Refactoring has profoundly changed how people think about software architecture. Early in my career, I was taught that software design and architecture was something to be worked on, and mostly completed, before anyone started writing code. Once the code was written, its architecture was fixed and could only decay due to carelessness.

Refactoring changes this perspective. It allows me to significantly alter the architecture of software that's been running in production for years. Refactoring can improve the design of existing code, as this book's subtitle implies. But as I indicated earlier, changing legacy code is often challenging, especially when it lacks decent tests.

The real impact of refactoring on architecture is in how it can be used to form a well-designed code base that can respond gracefully to changing needs. The biggest issue with finishing architecture before coding is that such an approach assumes the requirements for the software can be understood early on. But experience shows that this is often, even usually, an unachievable goal. Repeatedly, I saw people only understand what they really needed from software once they'd had a chance to use it, and saw the impact it made to their work.

One way of dealing with future changes is to put flexibility mechanisms into the software. As I write some function, I can see that it has a general applicability. To handle the different circumstances that I anticipate it to be used in, I can see a dozen parameters I could add to that function. These parameters are flexibility mechanisms—and, like most mechanisms, they are not a free lunch. Adding all those parameters complicates the function for the one case it's used right now. If I miss a parameter, all the parameterization I have added makes it harder for me to add more. I find I often get my flexibility mechanisms wrong—either because the changing needs didn't work out the way I expected or my mechanism design was faulty. Once I take all that into account, most of the time my flexibility mechanisms actually *slow down* my ability to react to change.

With refactoring, I can use a different strategy. Instead of speculating on what flexibility I will need in the future and what mechanisms will best enable that, I build software that solves only the currently understood needs, but I make this software excellently designed for those needs. As my understanding of the users' needs changes, I use refactoring to adapt the architecture to those new demands. I can happily include mechanisms that don't increase complexity (such as small, well-named functions) but any flexibility that complicates the software has to prove itself before I include it. If I don't have different values for a parameter from the callers, I don't add it to the parameter list. Should the time come that I need to add it, then *Parameterize Function* (310) is an easy refactoring to apply. I often find it useful to estimate how hard it would be to use refactoring later to support an anticipated change. Only if I can see that it would be substantially harder to refactor later do I consider adding a flexibility mechanism now.

This approach to design goes under various names: simple design, incremental design, or yagni [mf-yagni] (originally an acronym for “you aren’t going to need it”). Yagni doesn’t imply that architectural thinking disappears, although it is sometimes naively applied that way. I think of yagni as a different style of incorporating architecture and design into the development process—a style that isn’t credible without the foundation of refactoring.

Adopting yagni doesn’t mean I neglect all upfront architectural thinking. There are still cases where refactoring changes are difficult and some preparatory thinking can save time. But the balance has shifted a long way—I’m much more inclined to deal with issues later when I understand them better. All this has led to a growing discipline of evolutionary architecture [Ford et al.] where architects explore the patterns and practices that take advantage of our ability to iterate over architectural decisions.

Refactoring and the Wider Software Development Process

If you’ve read the earlier section on problems, one lesson you’ve probably drawn is that the effectiveness of refactoring is tied to other software practices that a team uses. Indeed, refactoring’s early adoption was as part of Extreme Programming [mf-xp] (XP), a process which was notable for putting together a set of relatively unusual and interdependent practices—such as continuous integration, self-testing code, and refactoring (the latter two woven into test-driven development).

Extreme Programming was one of the first agile software methods [mf-nm] and, for several years, led the rise of agile techniques. Enough projects now use agile methods that agile thinking is generally regarded as mainstream—but in reality most “agile” projects only use the name. To really operate in an agile way, a team has to be capable and enthusiastic refactorers—and for that, many aspects of their process have to align with making refactoring a regular part of their work.

The first foundation for refactoring is self-testing code. By this, I mean that there is a suite of automated tests that I can run and be confident that, if I made an error in my programming, some test will fail. This is such an important foundation for refactoring that I’ll spend a chapter talking more about this.

To refactor on a team, it’s important that each member can refactor when they need to without interfering with others’ work. This is why I encourage Continuous Integration. With CI, each member’s refactoring efforts are quickly shared with their colleagues. No one ends up building new work on interfaces that are being removed, and if the refactoring is going to cause a problem with someone else’s work, we know about this quickly. Self-testing code is also a key element of Continuous Integration, so there is a strong synergy between the three practices of self-testing code, continuous integration, and refactoring.

With this trio of practices in place, we enable the Yagni design approach that I talked about in the previous section. Refactoring and yagni positively reinforce each other: Not just is refactoring (and its prerequisites) a foundation for yagni—yagni makes it easier to do refactoring. This is because it's easier to change a simple system than one that has lots of speculative flexibility included. Balance these practices, and you can get into a virtuous circle with a code base that responds rapidly to changing needs and is reliable.

With these core practices in place, we have the foundation to take advantage of the other elements of the agile mindset. Continuous Delivery keeps our software in an always-releasable state. This is what allows many web organizations to release updates many times a day—but even if we don't need that, it reduces risk and allows us to schedule our releases to satisfy business needs rather than technological constraints. With a firm technical foundation, we can drastically reduce the time it takes to get a good idea into production code, allowing us to better serve our customers. Furthermore, these practices increase the reliability of our software, with less bugs to spend time fixing.

Stated like this, it all sounds rather simple—but in practice it isn't. Software development, whatever the approach, is a tricky business, with complex interactions between people and machines. The approach I describe here is a proven way to handle this complexity, but like any approach, it requires practice and skill.

Refactoring and Performance

A common concern with refactoring is the effect it has on the performance of a program. To make the software easier to understand, I often make changes that will cause the program to run slower. This is an important issue. I don't belong to the school of thought that ignores performance in favor of design purity or in hopes of faster hardware. Software has been rejected for being too slow, and faster machines merely move the goalposts. Refactoring can certainly make software go more slowly—but it also makes the software more amenable to performance tuning. The secret to fast software, in all but hard real-time contexts, is to write tunable software first and then tune it for sufficient speed.

I've seen three general approaches to writing fast software. The most serious of these is time budgeting, often used in hard real-time systems. As you decompose the design, you give each component a budget for resources—time and footprint. That component must not exceed its budget, although a mechanism for exchanging budgeted resources is allowed. Time budgeting focuses attention on hard performance times. It is essential for systems, such as heart pacemakers, in which late data is always bad data. This technique is inappropriate for other kinds of systems, such as the corporate information systems with which I usually work.

The second approach is the constant attention approach. Here, every programmer, all the time, does whatever she can to keep performance high. This is a common approach that is intuitively attractive—but it does not work very well. Changes that improve performance usually make the program harder to work with. This slows development. This would be a cost worth paying if the resulting software were quicker—but usually it is not. The performance improvements are spread all around the program; each improvement is made with a narrow perspective of the program's behavior, and often with a misunderstanding of how a compiler, runtime, and hardware behaves.

It Takes Awhile to Create Nothing

The Chrysler Comprehensive Compensation pay process was running too slowly. Although we were still in development, it began to bother us, because it was slowing down the tests.

Kent Beck, Martin Fowler, and I decided we'd fix it up. While I waited for us to get together, I was speculating, on the basis of my extensive knowledge of the system, about what was probably slowing it down. I thought of several possibilities and chatted with folks about the changes that were probably necessary. We came up with some really good ideas about what would make the system go faster.

Then we measured performance using Kent's profiler. None of the possibilities I had thought of had anything to do with the problem. Instead, we found that the system was spending half its time creating instances of date. Even more interesting was that all the instances had the same couple of values.

When we looked at the date-creation logic, we saw some opportunities for optimizing how these dates were created. They were all going through a string conversion even though no external inputs were involved. The code was just using string conversion for convenience of typing. Maybe we could optimize that.

Then we looked at how these dates were being used. It turned out that the huge bulk of them were all creating instances of date range, an object with a from date and a to date. Looking around little more, we realized that most of these date ranges were empty!

As we worked with date range, we used the convention that any date range that ended before it started was empty. It's a good convention and fits in well with how the class works. Soon after we started using this convention, we realized that just creating a date range that starts after it ends wasn't clear code, so we extracted that behavior into a factory method for empty date ranges.

We had made that change to make the code clearer, but we received an unexpected payoff. We created a constant empty date range and adjusted

the factory method to return that object instead of creating it every time. That change doubled the speed of the system, enough for the tests to be bearable. It took us about five minutes.

I had speculated with various members of the team (Kent and Martin deny participating in the speculation) on what was likely wrong with code we knew very well. We had even sketched some designs for improvements without first measuring what was going on.

We were completely wrong. Aside from having a really interesting conversation, we were doing no good at all.

The lesson is: Even if you know exactly what is going on in your system, measure performance, don't speculate. You'll learn something, and nine times out of ten, it won't be that you were right!

— Ron Jeffries

The interesting thing about performance is that in most programs, most of their time is spent in a small fraction of the code. If I optimize all the code equally, I'll end up with 90 percent of my work wasted because it's optimizing code that isn't run much. The time spent making the program fast—the time lost because of lack of clarity—is all wasted time.

The third approach to performance improvement takes advantage of this 90-percent statistic. In this approach, I build my program in a well-factored manner without paying attention to performance until I begin a deliberate performance optimization exercise. During this performance optimization, I follow a specific process to tune the program.

I begin by running the program under a profiler that monitors the program and tells me where it is consuming time and space. This way I can find that small part of the program where the performance hot spots lie. I then focus on those performance hot spots using the same optimizations I would use in the constant-attention approach. But since I'm focusing my attention on a hot spot, I'm getting much more effect with less work. Even so, I remain cautious. As in refactoring, I make the changes in small steps. After each step I compile, test, and rerun the profiler. If I haven't improved performance, I back out the change. I continue the process of finding and removing hot spots until I get the performance that satisfies my users.

Having a well-factored program helps with this style of optimization in two ways. First, it gives me time to spend on performance tuning. With well-factored code, I can add functionality more quickly. This gives me more time to focus on performance. (Profiling ensures I spend that time on the right place.) Second, with a well-factored program I have finer granularity for my performance analysis. My profiler leads me to smaller parts of the code, which are easier to tune. With clearer code, I have a better understanding of my options and of what kind of tuning will work.

I've found that refactoring helps me write fast software. It slows the software in the short term while I'm refactoring, but makes it easier to tune during optimization. I end up well ahead.

Where Did Refactoring Come From?

I've not succeeded in pinning down the birth of the term "refactoring." Good programmers have always spent at least some time cleaning up their code. They do this because they have learned that clean code is easier to change than complex and messy code, and good programmers know that they rarely write clean code the first time around.

Refactoring goes beyond this. In this book, I'm advocating refactoring as a key element in the whole process of software development. Two of the first people to recognize the importance of refactoring were Ward Cunningham and Kent Beck, who worked with Smalltalk from the 1980s onward. Smalltalk is an environment that even then was particularly hospitable to refactoring. It is a very dynamic environment that allows you to quickly write highly functional software. Smalltalk had a very short compile-link-execute cycle for its time, which made it easy to change things quickly at a time where overnight compile cycles were not unknown. It is also object-oriented and thus provides powerful tools for minimizing the impact of change behind well-defined interfaces. Ward and Kent explored software development approaches geared to this kind of environment, and their work developed into Extreme Programming. They realized that refactoring was important in improving their productivity and, ever since, have been working with refactoring, applying it to serious software projects and refining it.

Ward and Kent's ideas were a strong influence on the Smalltalk community, and the notion of refactoring became an important element in the Smalltalk culture. Another leading figure in the Smalltalk community is Ralph Johnson, a professor at the University of Illinois at Urbana-Champaign, who is famous as one of the authors of the "Gang of Four" [gof] book on design patterns. One of Ralph's biggest interests is in developing software frameworks. He explored how refactoring can help develop an efficient and flexible framework.

Bill Opdyke was one of Ralph's doctoral students and was particularly interested in frameworks. He saw the potential value of refactoring and saw that it could be applied to much more than Smalltalk. His background was in telephone switch development, in which a great deal of complexity accrues over time and changes are difficult to make. Bill's doctoral research looked at refactoring from a tool builder's perspective. Bill was interested in refactorings that would be useful for C++ framework development; he researched the necessary semantics-preserving refactorings and showed how to prove they were semantics-preserving and how a tool could implement these ideas. Bill's doctoral thesis [Opdyke] was the first substantial work on refactoring.

I remember meeting Bill at the OOPSLA conference in 1992. We sat in a café and he told me about his research. I remember thinking, “Interesting, but not really that important.” Boy, was I wrong!

John Brant and Don Roberts took the refactoring tool ideas much further to produce the Refactoring Browser, the first refactoring tool, appropriately for the Smalltalk environment.

And me? I’d always been inclined to clean code, but I’d never considered it to be that important. Then, I worked on a project with Kent and saw the way he used refactoring. I saw the difference it made in productivity and quality. That experience convinced me that refactoring was a very important technique. I was frustrated, however, because there was no book that I could give to a working programmer, and none of the experts above had any plans to write such a book. So, with their help, I did—which led to the first edition of this book.

Fortunately, the concept of refactoring caught on in the industry. The book sold well, and refactoring entered the vocabulary of most programmers. More tools appeared, especially for Java. One downside of this popularity has been people using “refactoring” loosely, to mean any kind of restructuring. Despite this, however, it has become a mainstream practice.

Automated Refactorings

Perhaps the biggest change to refactoring in the last decade or so is the availability of tools that support automated refactoring. If I want to rename a method in Java and I’m using IntelliJ IDEA [intellij] or Eclipse [eclipse] (to mention just two), I can do it by picking an item off the menu. The tool completes the refactoring for me—and I’m usually sufficiently confident in its work that I don’t bother running the test suite.

The first tool that did this was the Smalltalk Refactoring Browser, written by John Brandt and Don Roberts. The idea took off in the Java community very rapidly at the beginning of the century. When JetBrains launched their IntelliJ IDEA IDE, automated refactoring was one of the compelling features. IBM followed suit shortly afterwards with refactoring tools in Visual Age for Java. Visual Age didn’t have a big impact, but much of its capabilities were reimplemented in Eclipse, including the refactoring support.

Refactoring also came to C#, initially via JetBrains’s Resharper, a plug-in for Visual Studio. Later on, the Visual Studio team added some refactoring capabilities.

It’s now pretty common to find some kind of refactoring support in editors and tools, although the actual capabilities vary a fair bit. Some of this variation is due to the tool, some is caused by the limitations of what you can do with automated refactoring in different languages. I’m not going to analyze the capabilities of different tools here, but I think it is worth talking a bit about some of the underlying principles.

A crude way to automate a refactoring is to do text manipulation, such as a search/replace to change a name, or some simple reorganizing of code for *Extract Variable* (119). This is a very crude approach that certainly can't be trusted without rerunning tests. It can, however, be a handy first step. I'll use such macros in Emacs to speed up my refactoring work when I don't have more sophisticated refactorings available to me.

To do refactoring properly, the tool has to operate on the syntax tree of the code, not on the text. Manipulating the syntax tree is much more reliable to preserve what the code is doing. This is why at the moment, most refactoring capabilities are part of powerful IDEs—they use the syntax tree not just for refactoring but also for code navigation, linting, and the like. This collaboration between text and syntax tree is what takes them beyond text editors.

Refactoring isn't just understanding and updating the syntax tree. The tool also needs to figure out how to rerender the code into text back in the editor view. All in all, implementing decent refactoring is a challenging programming exercise—one that I'm mostly unaware of as I gaily use the tools.

Many refactorings are made much safer when applied in a language with static typing. Consider the simple *Rename Function* (124). I might have `addClient` methods on my `Salesman` class and on my `Server` class. I want to rename the one on my `salesman`, but it is different in intent from the one on my `server`, which I don't want to rename. Without static typing, the tool will find it difficult to tell whether any call to `addClient` is intended for the `salesman`. In the refactoring browser, it would generate a list of call sites and I would manually decide which ones to change. This makes it a nonsafe refactoring that forces me to rerun the tests. Such a tool is still helpful—but the equivalent operation in Java can be completely safe and automatic. Since the tool can resolve the method to the correct class with static typing, I can be confident that the tool changes only the methods it ought to.

Tools often go further. If I rename a variable, I can be prompted for changes to comments that use that name. If I use *Extract Function* (106), the tool spots some code that duplicates the new function's body and offers to replace it with a call. Programming with powerful refactorings like this is a compelling reason to use an IDE rather than stick with a familiar text editor. Personally I'm a big user of Emacs, but when working in Java I prefer IntelliJ IDEA or Eclipse—in large part due to the refactoring support.

While sophisticated refactoring tools are almost magical in their ability to safely refactor code, there are some edge cases where they slip up. Less mature tools struggle with reflective calls, such as `Method.invoke` in Java (although more mature tools handle this quite well). So even with mostly safe refactorings, it's wise to run the test suite every so often to ensure nothing has gone pear-shaped. Usually I'm refactoring with a mix of automated and manual refactorings, so I run my tests often enough.

The power of using the syntax tree to analyze and refactor programs is a compelling advantage for IDEs over simple text editors, but many programmers

prefer the flexibility of their favorite text editor and would like to have both. A technology that's currently gaining momentum is Language Servers [langserver]: software that will form a syntax tree and present an API to text editors. Such language servers can support many text editors and provide commands to do sophisticated code analysis and refactoring operations.

Going Further

It seems a little strange to be talking about further reading in only the second chapter, but this is as good a spot as any to point out there is more material out there on refactoring that goes beyond the basics in this book.

This book has taught refactoring to many people, but I have focused more on a refactoring reference than on taking readers through the learning process. If you are looking for such a book, I suggest Bill Wake's *Refactoring Workbook* [Wake] that contains many exercises to practice refactoring.

Many of those who pioneered refactoring were also active in the software patterns community. Josh Kerievsky tied these two worlds closely together with *Refactoring to Patterns* [Kerievsky], which looks at the most valuable patterns from the hugely influential "Gang of Four" book [gof] and shows how to use refactoring to evolve towards them.

This book concentrates on refactoring in general-purpose programming, but refactoring also applies in specialized areas. Two that have got useful attention are *Refactoring Databases* [Ambler & Sadalage] (by Scott Ambler and Pramod Sadalage) and *Refactoring HTML* [Harold] (by Elliotte Rusty Harold).

Although it doesn't have refactoring in the title, also worth including is Michael Feathers's *Working Effectively with Legacy Code* [Feathers], which is primarily a book about how to think about refactoring an older codebase with poor test coverage.

Although this book (and its predecessor) are intended for programmers with any language, there is a place for language-specific refactoring books. Two of my former colleagues, Jay Fields and Shane Harvey, did this for the Ruby programming language [Fields et al.].

For more up-to-date material, look up the web representation of this book, as well as the main refactoring web site: refactoring.com [ref.com].

Chapter 3

Bad Smells in Code

by Kent Beck and Martin Fowler

*“If it stinks, change it.”
— Grandma Beck, discussing child-rearing philosophy*

By now you have a good idea of how refactoring works. But just because you know how doesn’t mean you know when. Deciding when to start refactoring—and when to stop—is just as important to refactoring as knowing how to operate the mechanics of it.

Now comes the dilemma. It is easy to explain how to delete an instance variable or create a hierarchy. These are simple matters. Trying to explain *when* you should do these things is not so cut-and-dried. Instead of appealing to some vague notion of programming aesthetics (which, frankly, is what we consultants usually do), I wanted something a bit more solid.

When I was writing the first edition of this book, I was mulling over this issue as I visited Kent Beck in Zurich. Perhaps he was under the influence of the odors of his newborn daughter at the time, but he had come up with the notion of describing the “when” of refactoring in terms of smells.

“Smells,” you say, “and that is supposed to be better than vague aesthetics?” Well, yes. We have looked at lots of code, written for projects that span the gamut from wildly successful to nearly dead. In doing so, we have learned to look for certain structures in the code that suggest—sometimes, scream for—the possibility of refactoring. (We are switching over to “we” in this chapter to reflect the fact that Kent and I wrote this chapter jointly. You can tell the difference because the funny jokes are mine and the others are his.)

One thing we won’t try to give you is precise criteria for when a refactoring is overdue. In our experience, no set of metrics rivals informed human intuition. What we will do is give you indications that there is trouble that can be solved by a refactoring. You will have to develop your own sense of how many instance variables or how many lines of code in a method are too many.

Use this chapter and the table on the inside back cover as a way to give you inspiration when you’re not sure what refactorings to do. Read the chapter (or

skim the table) and try to identify what it is you're smelling, then go to the refactorings we suggest to see whether they will help you. You may not find the exact smell you can detect, but hopefully it should point you in the right direction.

Mysterious Name

Puzzling over some text to understand what's going on is a great thing if you're reading a detective novel, but not when you're reading code. We may fantasize about being International Men of Mystery, but our code needs to be mundane and clear. One of the most important parts of clear code is good names, so we put a lot of thought into naming functions, modules, variables, classes, so they clearly communicate what they do and how to use them.

Sadly, however, naming is one of the two hard things [mf-2h] in programming. So, perhaps the most common refactorings we do are the renames: *Change Function Declaration* (124) (to rename a function), *Rename Variable* (137), and *Rename Field* (244). People are often afraid to rename things, thinking it's not worth the trouble, but a good name can save hours of puzzled incomprehension in the future.

Renaming is not just an exercise in changing names. When you can't think of a good name for something, it's often a sign of a deeper design malaise. Puzzling over a tricky name has often led us to significant simplifications to our code.

Duplicated Code

If you see the same code structure in more than one place, you can be sure that your program will be better if you find a way to unify them. Duplication means that every time you read these copies, you need to read them carefully to see if there's any difference. If you need to change the duplicated code, you have to find and catch each duplication.

The simplest duplicated code problem is when you have the same expression in two methods of the same class. Then all you have to do is *Extract Function* (106) and invoke the code from both places. If you have code that's similar, but not quite identical, see if you can use *Slide Statements* (223) to arrange the code so the similar items are all together for easy extraction. If the duplicate fragments are in subclasses of a common base class, you can use *Pull Up Method* (350) to avoid calling one from another.

Long Function

In our experience, the programs that live best and longest are those with short functions. Programmers new to such a code base often feel that no computation ever takes place—that the program is an endless sequence of delegation. When you have lived with such a program for a few years, however, you learn just how valuable all those little functions are. All of the payoffs of indirection—explanation, sharing, and choosing—are supported by small functions.

Since the early days of programming, people have realized that the longer a function is, the more difficult it is to understand. Older languages carried an overhead in subroutine calls, which deterred people from small functions. Modern languages have pretty much eliminated that overhead for in-process calls. There is still overhead for the reader of the code because you have to switch context to see what the function does. Development environments that allow you to quickly jump between a function call and its declaration, or to see both functions at once, help eliminate this step, but the real key to making it easy to understand small functions is good naming. If you have a good name for a function, you mostly don't need to look at its body.

The net effect is that you should be much more aggressive about decomposing functions. A heuristic we follow is that whenever we feel the need to comment something, we write a function instead. Such a function contains the code that we wanted to comment but is named after the *intention* of the code rather than the way it works. We may do this on a group of lines or even on a single line of code. We do this even if the method call is longer than the code it replaces—provided the method name explains the purpose of the code. The key here is not function length but the semantic distance between what the method does and how it does it.

Ninety-nine percent of the time, all you have to do to shorten a function is *Extract Function (106)*. Find parts of the function that seem to go nicely together and make a new one.

If you have a function with lots of parameters and temporary variables, they get in the way of extracting. If you try to use *Extract Function (106)*, you end up passing so many parameters to the extracted method that the result is scarcely more readable than the original. You can often use *Replace Temp with Query (178)* to eliminate the temps. Long lists of parameters can be slimmed down with *Introduce Parameter Object (140)* and *Preserve Whole Object (319)*.

If you've tried that and you still have too many temps and parameters, it's time to get out the heavy artillery: *Replace Function with Command (337)*.

How do you identify the clumps of code to extract? A good technique is to look for comments. They often signal this kind of semantic distance. A block of code with a comment that tells you what it is doing can be replaced by a method whose name is based on the comment. Even a single line is worth extracting if it needs explanation.

Conditionals and loops also give signs for extractions. Use *Decompose Conditional* (260) to deal with conditional expressions. A big switch statement should have its legs turned into single function calls with *Extract Function* (106). If there's more than one switch statement switching on the same condition, you should apply *Replace Conditional with Polymorphism* (272).

With loops, extract the loop and the code within the loop into its own method. If you find it hard to give an extracted loop a name, that may be because it's doing two different things—in which case don't be afraid to use *Split Loop* (227) to break out the separate tasks.

Long Parameter List

In our early programming days, we were taught to pass in as parameters everything needed by a function. This was understandable because the alternative was global data, and global data quickly becomes evil. But long parameter lists are often confusing in their own right.

If you can obtain one parameter by asking another parameter for it, you can use *Replace Parameter with Query* (324) to remove the second parameter. Rather than pulling lots of data out of an existing data structure, you can use *Preserve Whole Object* (319) to pass the original data structure instead. If several parameters always fit together, combine them with *Introduce Parameter Object* (140). If a parameter is used as a flag to dispatch different behavior, use *Remove Flag Argument* (314).

Classes are a great way to reduce parameter list sizes. They are particularly useful when multiple functions share several parameter values. Then, you can use *Combine Functions into Class* (144) to capture those common values as fields. If we put on our functional programming hats, we'd say this creates a set of partially applied functions.

Global Data

Since our earliest days of writing software, we were warned of the perils of global data—how it was invented by demons from the fourth plane of hell, which is the resting place of any programmer who dares to use it. And, although we are somewhat skeptical about fire and brimstone, it's still one of the most pungent odors we are likely to run into. The problem with global data is that it can be modified from anywhere in the code base, and there's no mechanism to discover which bit of code touched it. Time and again, this leads to bugs that breed from a form of spooky action from a distance—and it's very hard to find out where the errant bit of program is. The most obvious form of global data is global variables, but we also see this problem with class variables and singletons.

Our key defense here is *Encapsulate Variable (132)*, which is always our first move when confronted with data that is open to contamination by any part of a program. At least when you have it wrapped by a function, you can start seeing where it's modified and start to control its access. Then, it's good to limit its scope as much as possible by moving it within a class or module where only that module's code can see it.

Global data is especially nasty when it's mutable. Global data that you can guarantee never changes after the program starts is relatively safe—if you have a language that can enforce that guarantee.

Global data illustrates Paracelsus's maxim: The difference between a poison and something benign is the dose. You can get away with small doses of global data, but it gets exponentially harder to deal with the more you have. Even with little bits, we like to keep it encapsulated—that's the key to coping with changes as the software evolves.

Mutable Data

Changes to data can often lead to unexpected consequences and tricky bugs. I can update some data here, not realizing that another part of the software expects something different and now fails—a failure that's particularly hard to spot if it only happens under rare conditions. For this reason, an entire school of software development—functional programming—is based on the notion that data should never change and that updating a data structure should always return a new copy of the structure with the change, leaving the old data pristine.

These kinds of languages, however, are still a relatively small part of programming; many of us work in languages that allow variables to vary. But this doesn't mean we should ignore the advantages of immutability—there are still many things we can do to limit the risks on unrestricted data updates.

You can use *Encapsulate Variable (132)* to ensure that all updates occur through narrow functions that can be easier to monitor and evolve. If a variable is being updated to store different things, use *Split Variable (240)* both to keep them separate and avoid the risky update. Try as much as possible to move logic out of code that processes the update by using *Slide Statements (223)* and *Extract Function (106)* to separate the side-effect-free code from anything that performs the update. In APIs, use *Separate Query from Modifier (306)* to ensure callers don't need to call code that has side effects unless they really need to. We like to use *Remove Setting Method (331)* as soon as we can—sometimes, just trying to find clients of a setter helps spot opportunities to reduce the scope of a variable.

Mutable data that can be calculated elsewhere is particularly pungent. It's not just a rich source of confusion, bugs, and missed dinners at home—it's also unnecessary. We spray it with a concentrated solution of vinegar and *Replace Derived Variable with Query (248)*.

Mutable data isn't a big problem when it's a variable whose scope is just a couple of lines—but its risk increases as its scope grows. Use *Combine Functions into Class* (144) or *Combine Functions into Transform* (149) to limit how much code needs to update a variable. If a variable contains some data with internal structure, it's usually better to replace the entire structure rather than modify it in place, using *Change Reference to Value* (252).

Divergent Change

We structure our software to make change easier; after all, software is meant to be soft. When we make a change, we want to be able to jump to a single clear point in the system and make the change. When you can't do this, you are smelling one of two closely related pungencies.

Divergent change occurs when one module is often changed in different ways for different reasons. If you look at a module and say, "Well, I will have to change these three functions every time I get a new database; I have to change these four functions every time there is a new financial instrument," this is an indication of divergent change. The database interaction and financial processing problems are separate contexts, and we can make our programming life better by moving such contexts into separate modules. That way, when we have a change to one context, we only have to understand that one context and ignore the other. We always found this to be important, but now, with our brains shrinking with age, it becomes all the more imperative. Of course, you often discover this only after you've added a few databases or financial instruments; context boundaries are usually unclear in the early days of a program and continue to shift as a software system's capabilities change.

If the two aspects naturally form a sequence—for example, you get data from the database and then apply your financial processing on it—then *Split Phase* (154) separates the two with a clear data structure between them. If there's more back-and-forth in the calls, then create appropriate modules and use *Move Function* (198) to divide the processing up. If functions mix the two types of processing within themselves, use *Extract Function* (106) to separate them before moving. If the modules are classes, then *Extract Class* (182) helps formalize how to do the split.

Shotgun Surgery

Shotgun surgery is similar to divergent change but is the opposite. You whiff this when, every time you make a change, you have to make a lot of little edits to a

lot of different classes. When the changes are all over the place, they are hard to find, and it's easy to miss an important change.

In this case, you want to use *Move Function (198)* and *Move Field (207)* to put all the changes into a single module. If you have a bunch of functions operating on similar data, use *Combine Functions into Class (144)*. If you have functions that are transforming or enriching a data structure, use *Combine Functions into Transform (149)*. *Split Phase (154)* is often useful here if the common functions can combine their output for a consuming phase of logic.

A useful tactic for shotgun surgery is to use inlining refactorings, such as *Inline Function (115)* or *Inline Class (186)*, to pull together poorly separated logic. You'll end up with a Long Method or a Large Class, but can then use extractions to break it up into more sensible pieces. Even though we are inordinately fond of small functions and classes in our code, we aren't afraid of creating something large as an intermediate step to reorganization.

Feature Envy

When we modularize a program, we are trying to separate the code into zones to maximize the interaction inside a zone and minimize interaction between zones. A classic case of Feature Envy occurs when a function in one module spends more time communicating with functions or data inside another module than it does within its own module. We've lost count of the times we've seen a function invoking half-a-dozen getter methods on another object to calculate some value. Fortunately, the cure for that case is obvious: The function clearly wants to be with the data, so use *Move Function (198)* to get it there. Sometimes, only a part of a function suffers from envy, in which case use *Extract Function (106)* on the jealous bit, and *Move Function (198)* to give it a dream home.

Of course not all cases are cut-and-dried. Often, a function uses features of several modules, so which one should it live with? The heuristic we use is to determine which module has most of the data and put the function with that data. This step is often made easier if you use *Extract Function (106)* to break the function into pieces that go into different places.

Of course, there are several sophisticated patterns that break this rule. From the Gang of Four [gof], Strategy and Visitor immediately leap to mind. Kent Beck's Self Delegation [Beck SBPP] is another. Use these to combat the divergent change smell. The fundamental rule of thumb is to put things together that change together. Data and the behavior that references that data usually change together—but there are exceptions. When the exceptions occur, we move the behavior to keep changes in one place. Strategy and Visitor allow you to change behavior easily because they isolate the small amount of behavior that needs to be overridden, at the cost of further indirection.

Data Clumps

Data items tend to be like children: They enjoy hanging around together. Often, you'll see the same three or four data items together in lots of places: as fields in a couple of classes, as parameters in many method signatures. Bunches of data that hang around together really ought to find a home together. The first step is to look for where the clumps appear as fields. Use *Extract Class* (182) on the fields to turn the clumps into an object. Then turn your attention to method signatures using *Introduce Parameter Object* (140) or *Preserve Whole Object* (319) to slim them down. The immediate benefit is that you can shrink a lot of parameter lists and simplify method calling. Don't worry about data clumps that use only some of the fields of the new object. As long as you are replacing two or more fields with the new object, you'll come out ahead.

A good test is to consider deleting one of the data values. If you did this, would the others make any sense? If they don't, it's a sure sign that you have an object that's dying to be born.

You'll notice that we advocate creating a class here, not a simple record structure. We do this because using a class gives you the opportunity to make a nice perfume. You can now look for cases of feature envy, which will suggest behavior that can be moved into your new classes. We've often seen this as a powerful dynamic that creates useful classes and can remove a lot of duplication and accelerate future development, allowing the data to become productive members of society.

Primitive Obsession

Most programming environments are built on a widely used set of primitive types: integers, floating point numbers, and strings. Libraries may add some additional small objects such as dates. We find many programmers are curiously reluctant to create their own fundamental types which are useful for their domain—such as money, coordinates, or ranges. We thus see calculations that treat monetary amounts as plain numbers, or calculations of physical quantities that ignore units (adding inches to millimeters), or lots of code doing `if (a < upper && a > lower)`.

Strings are particularly common petri dishes for this kind of odor: A telephone number is more than just a collection of characters. If nothing else, a proper type can often include consistent display logic for when it needs to be displayed in a user interface. Representing such types as strings is such a common stench that people call them “stringly typed” variables.

You can move out of the primitive cave into the centrally heated world of meaningful types by using *Replace Primitive with Object* (174). If the primitive is a type code controlling conditional behavior, use *Replace Type Code with Subclasses* (362) followed by *Replace Conditional with Polymorphism* (272).

Groups of primitives that commonly appear together are data clumps and should be civilized with *Extract Class* (182) and *Introduce Parameter Object* (140).

Repeated Switches

Talk to a true object-oriented evangelist and they'll soon get onto the evils of switch statements. They'll argue that any switch statement you see is begging for *Replace Conditional with Polymorphism* (272). We've even heard some people argue that all conditional logic should be replaced with polymorphism, tossing most ifs into the dustbin of history.

Even in our more wild-eyed youth, we were never unconditionally opposed to the conditional. Indeed, the first edition of this book had a smell entitled "switch statements." The smell was there because in the late 90's we found polymorphism sadly underappreciated, and saw benefit in getting people to switch over.

These days there is more polymorphism about, and it isn't the simple red flag that it often was fifteen years ago. Furthermore, many languages support more sophisticated forms of switch statements that use more than some primitive code as their base. So we now focus on the repeated switch, where the same conditional switching logic (either in a switch/case statement or in a cascade of if/else statements) pops up in different places. The problem with such duplicate switches is that, whenever you add a clause, you have to find all the switches and update them. Against the dark forces of such repetition, polymorphism provides an elegant weapon for a more civilized codebase.

Loops

Loops have been a core part of programming since the earliest languages. But we feel they are no more relevant today than bell-bottoms and flock wallpaper. We disdained them at the time of the first edition—but Java, like most other languages at the time, didn't provide a better alternative. These days, however, first-class functions are widely supported, so we can use *Replace Loop with Pipeline* (231) to retire those anachronisms. We find that pipeline operations, such as filter and map, help us quickly see the elements that are included in the processing and what is done with them.

Lazy Element

We like using program elements to add structure—providing opportunities for variation, reuse, or just having more helpful names. But sometimes the structure isn't needed. It may be a function that's named the same as its body code reads, or a class that is essentially one simple function. Sometimes, this reflects a function that was expected to grow and be popular later, but never realized its dreams. Sometimes, it's a class that used to pay its way, but has been downsized with refactoring. Either way, such program elements need to die with dignity. Usually this means using *Inline Function (115)* or *Inline Class (186)*. With inheritance, you can use *Collapse Hierarchy (380)*.

Speculative Generality

Brian Foote suggested this name for a smell to which we are very sensitive. You get it when people say, “Oh, I think we'll need the ability to do this kind of thing someday” and thus add all sorts of hooks and special cases to handle things that aren't required. The result is often harder to understand and maintain. If all this machinery were being used, it would be worth it. But if it isn't, it isn't. The machinery just gets in the way, so get rid of it.

If you have abstract classes that aren't doing much, use *Collapse Hierarchy (380)*. Unnecessary delegation can be removed with *Inline Function (115)* and *Inline Class (186)*. Functions with unused parameters should be subject to *Change Function Declaration (124)* to remove those parameters. You should also apply *Change Function Declaration (124)* to remove any unneeded parameters, which often get tossed in for future variations that never come to pass.

Speculative generality can be spotted when the only users of a function or class are test cases. If you find such an animal, delete the test case and apply *Remove Dead Code (237)*.

Temporary Field

Sometimes you see a class in which a field is set only in certain circumstances. Such code is difficult to understand, because you expect an object to need all of its fields. Trying to understand why a field is there when it doesn't seem to be used can drive you nuts.

Use *Extract Class (182)* to create a home for the poor orphan variables. Use *Move Function (198)* to put all the code that concerns the fields into this new class.

You may also be able to eliminate conditional code by using *Introduce Special Case (289)* to create an alternative class for when the variables aren't valid.

Message Chains

You see message chains when a client asks one object for another object, which the client then asks for yet another object, which the client then asks for yet another another object, and so on. You may see these as a long line of `getThis` methods, or as a sequence of temps. Navigating this way means the client is coupled to the structure of the navigation. Any change to the intermediate relationships causes the client to have to change.

The move to use here is *Hide Delegate (189)*. You can do this at various points in the chain. In principle, you can do this to every object in the chain, but doing this often turns every intermediate object into a middle man. Often, a better alternative is to see what the resulting object is used for. See whether you can use *Extract Function (106)* to take a piece of the code that uses it and then *Move Function (198)* to push it down the chain. If several clients of one of the objects in the chain want to navigate the rest of the way, add a method to do that.

Some people consider any method chain to be a terrible thing. We are known for our calm, reasoned moderation. Well, at least in this case we are.

Middle Man

One of the prime features of objects is encapsulation—hiding internal details from the rest of the world. Encapsulation often comes with delegation. You ask a director whether she is free for a meeting; she delegates the message to her diary and gives you an answer. All well and good. There is no need to know whether the director uses a diary, an electronic gizmo, or a secretary to keep track of her appointments.

c However, this can go too far. You look at a class's interface and find half the methods are delegating to this other class. After a while, it is time to use *Remove Middle Man (192)* and talk to the object that really knows what's going on. If only a few methods aren't doing much, use *Inline Function (115)* to inline them into the caller. If there is additional behavior, you can use *Replace Superclass with Delegate (399)* or *Replace Subclass with Delegate (381)* to fold the middle man into the real object. That allows you to extend behavior without chasing all that delegation.

Insider Trading

Software people like strong walls between their modules and complain bitterly about how trading data around too much increases coupling. To make things work, some trade has to occur, but we need to reduce it to a minimum and keep it all above board.

Modules that whisper to each other by the coffee machine need to be separated by using *Move Function* (198) and *Move Field* (207) to reduce the need to chat. If modules have common interests, try to create a third module to keep that commonality in a well-regulated vehicle, or use *Hide Delegate* (189) to make another module act as an intermediary.

Inheritance can often lead to collusion. Subclasses are always going to know more about their parents than their parents would like them to know. If it's time to leave home, apply *Replace Subclass with Delegate* (381) or *Replace Superclass with Delegate* (399).

Large Class

When a class is trying to do too much, it often shows up as too many fields. When a class has too many fields, duplicated code cannot be far behind.

You can *Extract Class* (182) to bundle a number of the variables. Choose variables to go together in the component that makes sense for each. For example, "depositAmount" and "depositCurrency" are likely to belong together in a component. More generally, common prefixes or suffixes for some subset of the variables in a class suggest the opportunity for a component. If the component makes sense with inheritance, you'll find *Extract Superclass* (375) or *Replace Type Code with Subclasses* (362) (which essentially is extracting a subclass) are often easier.

Sometimes a class does not use all of its fields all of the time. If so, you may be able to do these extractions many times.

As with a class with too many instance variables, a class with too much code is a prime breeding ground for duplicated code, chaos, and death. The simplest solution (have we mentioned that we like simple solutions?) is to eliminate redundancy in the class itself. If you have five hundred-line methods with lots of code in common, you may be able to turn them into five ten-line methods with another ten two-line methods extracted from the original.

The clients of such a class are often the best clue for splitting up the class. Look at whether clients use a subset of the features of the class. Each subset is a possible separate class. Once you've identified a useful subset, use *Extract Class* (182), *Extract Superclass* (375), or *Replace Type Code with Subclasses* (362) to break it out.

Alternative Classes with Different Interfaces

One of the great benefits of using classes is the support for substitution, allowing one class to swap in for another in times of need. But this only works if their interfaces are the same. Use *Change Function Declaration* (124) to make functions match up. Often, this doesn't go far enough; keep using *Move Function* (198) to move behavior into classes until the protocols match. If this leads to duplication, you may be able to use *Extract Superclass* (375) to atone.

Data Class

These are classes that have fields, getting and setting methods for the fields, and nothing else. Such classes are dumb data holders and are often being manipulated in far too much detail by other classes. In some stages, these classes may have public fields. If so, you should immediately apply *Encapsulate Record* (162) before anyone notices. Use *Remove Setting Method* (331) on any field that should not be changed.

Look for where these getting and setting methods are used by other classes. Try to use *Move Function* (198) to move behavior into the data class. If you can't move a whole function, use *Extract Function* (106) to create a function that can be moved.

Data classes are often a sign of behavior in the wrong place, which means you can make big progress by moving it from the client into the data class itself. But there are exceptions, and one of the best exceptions is a record that's being used as a result record from a distinct function invocation. A good example of this is the intermediate data structure after you've applied *Split Phase* (154). A key characteristic of such a result record is that it's immutable (at least in practice). Immutable fields don't need to be encapsulated and information derived from immutable data can be represented as fields rather than getting methods.

Refused Bequest

Subclasses get to inherit the methods and data of their parents. But what if they don't want or need what they are given? They are given all these great gifts and pick just a few to play with.

The traditional story is that this means the hierarchy is wrong. You need to create a new sibling class and use *Push Down Method* (359) and *Push Down Field* (361) to push all the unused code to the sibling. That way the parent holds only what is common. Often, you'll hear advice that all superclasses should be abstract.

You'll guess from our snide use of "traditional" that we aren't going to advise this—at least not all the time. We do subclassing to reuse a bit of behavior all the time, and we find it a perfectly good way of doing business. There is a smell—we can't deny it—but usually it isn't a strong smell. So, we say that if the refused bequest is causing confusion and problems, follow the traditional advice. However, don't feel you have to do it all the time. Nine times out of ten this smell is too faint to be worth cleaning.

The smell of refused bequest is much stronger if the subclass is reusing behavior but does not want to support the interface of the superclass. We don't mind refusing implementations—but refusing interface gets us on our high horses. In this case, however, don't fiddle with the hierarchy; you want to gut it by applying *Replace Subclass with Delegate* (381) or *Replace Superclass with Delegate* (399).

Comments

Don't worry, we aren't saying that people shouldn't write comments. In our olfactory analogy, comments aren't a bad smell; indeed they are a sweet smell. The reason we mention comments here is that comments are often used as a deodorant. It's surprising how often you look at thickly commented code and notice that the comments are there because the code is bad.

Comments lead us to bad code that has all the rotten whiffs we've discussed in the rest of this chapter. Our first action is to remove the bad smells by refactoring. When we're finished, we often find that the comments are superfluous.

If you need a comment to explain what a block of code does, try *Extract Function* (106). If the method is already extracted but you still need a comment to explain what it does, use *Change Function Declaration* (124) to rename it. If you need to state some rules about the required state of the system, use *Introduce Assertion* (302).



When you feel the need to write a comment, first try to refactor the code so that any comment becomes superfluous.

A good time to use a comment is when you don't know what to do. In addition to describing what is going on, comments can indicate areas in which you aren't sure. A comment can also explain why you did something. This kind of information helps future modifiers, especially forgetful ones.

Chapter 4

Building Tests

Refactoring is a valuable tool, but it can't come alone. To do refactoring properly, I need a solid suite of tests to spot my inevitable mistakes. Even with automated refactoring tools, many of my refactorings will still need checking via a test suite.

I don't find this to be a disadvantage. Even without refactoring, writing good tests increases my effectiveness as a programmer. This was a surprise for me and is counterintuitive for most programmers—so it's worth explaining why.

The Value of Self-Testing Code

If you look at how most programmers spend their time, you'll find that writing code is actually quite a small fraction. Some time is spent figuring out what ought to be going on, some time is spent designing, but most time is spent debugging. I'm sure every reader can remember long hours of debugging—often, well into the night. Every programmer can tell a story of a bug that took a whole day (or more) to find. Fixing the bug is usually pretty quick, but finding it is a nightmare. And then, when you do fix a bug, there's always a chance that another one will appear and that you might not even notice it till much later. And you'll spend ages finding that bug.

The event that started me on the road to self-testing code was a talk at OOPSLA in 1992. Someone (I think it was “Bedarra” Dave Thomas) said offhandedly, “Classes should contain their own tests.” So I decided to incorporate tests into the code base together with the production code. As I was also doing iterative development, I tried adding tests as I completed each iteration. The project on which I was working at that time was quite small, so we put out iterations every week or so. Running the tests became fairly straightforward—but although it was easy, it was still pretty boring. This was because every test produced output to the console that I had to check. Now I'm a pretty lazy person and am prepared to work quite hard in order to avoid work. I realized that, instead of looking at the screen to see if it printed out some information from the model, I could get the

computer to make that test. All I had to do was put the output I expected in the test code and do a comparison. Now I could run the tests and they would just print “OK” to the screen if all was well. The software was now self-testing.



Make sure all tests are fully automatic and that they check their own results.

Now it was easy to run tests—as easy as compiling. So I started to run tests every time I compiled. Soon, I began to notice my productivity had shot upward. I realized that I wasn’t spending so much time debugging. If I added a bug that

was caught by a previous test, it would show up as soon as I ran that test. The test had worked before, so I would know that the bug was in the work I had done since I last tested. And I ran the tests frequently—which means only a few minutes had elapsed. I thus knew that the source of the bug was the code I had just written. As it was a small amount of code that was still fresh in my mind, the bug was easy to find. Bugs that would have otherwise taken an hour or more to find now took a couple of minutes at most. Not only was my software self-testing, but by running the tests frequently I had a powerful bug detector.

As I noticed this, I became more aggressive about doing the tests. Instead of waiting for the end of an increment, I would add the tests immediately after writing a bit of function. Every day I would add a couple of new features and the tests to test them. I hardly ever spent more than a few minutes hunting for a regression bug.



A suite of tests is a powerful bug detector that decapitates the time it takes to find bugs.

Tools for writing and organizing these tests have developed a great deal since my experiments. While flying from Switzerland to Atlanta for OOPSLA 1997, Kent Beck paired with Erich Gamma to port his unit testing framework from

Smalltalk to Java. The resulting framework, called JUnit, has been enormously influential for program testing, inspiring a huge variety of similar tools [mf-xunit] in lots of different languages.

Admittedly, it is not so easy to persuade others to follow this route. Writing the tests means a lot of extra code to write. Unless you have actually experienced how it speeds programming, self-testing does not seem to make sense. This is not helped by the fact that many people have never learned to write tests or even to think about tests. When tests are manual, they are gut-wrenchingly boring. But when they are automatic, tests can actually be quite fun to write.

In fact, one of the most useful times to write tests is before I start programming. When I need to add a feature, I begin by writing the test. This isn’t as backward as it sounds. By writing the test, I’m asking myself what needs to be done to add the function. Writing the test also concentrates me on the interface rather than the implementation (always a good thing). It also means I have a clear point at which I’m done coding—when the test works.

Kent Beck baked this habit of writing the test first into a technique called Test-Driven Development (TDD) [mf-tdd]. The Test-Driven Development approach to programming relies on short cycles of writing a (failing) test, writing the code to make that test work, and refactoring to ensure the result is as clean as possible. This test-code-refactor cycle should occur many times per hour, and can be a very productive and calming way to write code. I'm not going to discuss it further here, but I do use and warmly recommend it.

That's enough of the polemic. Although I believe everyone would benefit by writing self-testing code, it is not the point of this book. This book is about refactoring. Refactoring requires tests. If you want to refactor, you have to write tests. This chapter gives you a start in doing this for JavaScript. This is not a testing book, so I'm not going to go into much detail. I've found, however, that with testing a remarkably small amount of work can have surprisingly big benefits.

As with everything else in this book, I describe the testing approach using examples. When I develop code, I write the tests as I go. But sometimes, I need to refactor some code without tests—then I have to make the code self-testing before I begin.

Sample Code to Test

Here's some code to look at and test. The code supports a simple application that allows a user to examine and manipulate a production plan. The (crude) UI looks like this:

Province: **Asia**

demand: price:

3 producers:

Byzantium: cost: production: full revenue: 90

Attalia: cost: production: full revenue: 120

Sinope: cost: production: full revenue: 60

shortfall: **5** profit: **230**

The production plan has a demand and price for each province. Each province has producers, each of which can produce a certain number of units at a particular price. The UI also shows how much revenue each producer would earn if they sell all their production. At the bottom, the screen shows the shortfall in production (the demand minus the total production) and the profit for this plan. The UI allows the user to manipulate the demand, price, and the individual producer's production and costs to see the effect on the production shortfall and profits. Whenever a user changes any number in the display, all the others update immediately.

I'm showing a user interface here, so you can sense how the software is used, but I'm only going to concentrate on the business logic part of the software—that is, the classes that calculate the profit and the shortfall, not the code that generates the HTML and hooks up the field changes to the underlying business logic. This chapter is just an introduction to the world of self-testing code, so it makes sense for me to start with the easiest case—which is code that doesn't involve user interface, persistence, or external service interaction. Such separation, however, is a good idea in any case: Once this kind of business logic gets at all complicated, I will separate it from the UI mechanics so I can more easily reason about it and test it.

This business logic code involves two classes: one that represents a single producer, and the other that represents a whole province. The province's constructor takes a JavaScript object—one we could imagine being supplied by a JSON document.

Here's the code that loads the province from the JSON data:

```
class Province...
  constructor(doc) {
    this._name = doc.name;
    this._producers = [];
    this._totalProduction = 0;
    this._demand = doc.demand;
    this._price = doc.price;
    doc.producers.forEach(d => this.addProducer(new Producer(this, d)));
  }
  addProducer(arg) {
    this._producers.push(arg);
    this._totalProduction += arg.production;
  }
```

This function creates suitable JSON data. I can create a sample province for testing by constructing a province object with the result of this function.

top level...

```
function sampleProvinceData() {
  return {
    name: "Asia",
    producers: [
      {name: "Byzantium", cost: 10, production: 9},
      {name: "Attalia",   cost: 12, production: 10},
      {name: "Sinope",   cost: 10, production: 6},
    ],
    demand: 30,
    price: 20
  };
}
```

The province class has accessors for the various data values:

class Province...

```
get name() {return this._name;}
get producers() {return this._producers.slice();}
get totalProduction() {return this._totalProduction;}
set totalProduction(arg) {this._totalProduction = arg;}
get demand() {return this._demand;}
set demand(arg) {this._demand = parseInt(arg);}
get price() {return this._price;}
set price(arg) {this._price = parseInt(arg);}
```

The setters will be called with strings from the UI that contain the numbers, so I need to parse the numbers to use them reliably in calculations.

The producer class is mostly a simple data holder:

class Producer...

```
constructor(aProvince, data) {
  this._province = aProvince;
  this._cost = data.cost;
  this._name = data.name;
  this._production = data.production || 0;
}
get name() {return this._name;}
get cost() {return this._cost;}
set cost(arg) {this._cost = parseInt(arg);}

get production() {return this._production;}
set production(amountStr) {
  const amount = parseInt(amountStr);
  const newProduction = Number.isNaN(amount) ? 0 : amount;
  this._province.totalProduction += newProduction - this._production;
  this._production = newProduction;
}
```

The way that set production updates the derived data in the province is ugly, and whenever I see that I want to refactor to remove it. But I have to write tests before that I can refactor it.

The calculation for the shortfall is simple.

class Province...

```
get shortfall() {
  return this._demand - this.totalProduction;
}
```

That for the profit is a bit more involved.

class Province...

```
get profit() {
  return this.demandValue - this.demandCost;
}
get demandCost() {
  let remainingDemand = this.demand;
  let result = 0;
  this.producers
    .sort((a,b) => a.cost - b.cost)
    .forEach(p => {
      const contribution = Math.min(remainingDemand, p.production);
      remainingDemand -= contribution;
      result += contribution * p.cost;
    });
  return result;
}
get demandValue() {
  return this.satisfiedDemand * this.price;
}
get satisfiedDemand() {
  return Math.min(this._demand, this.totalProduction);
}
```

A First Test

To test this code, I'll need some sort of testing framework. There are many out there, even just for JavaScript. The one I'll use is Mocha [\[mocha\]](#), which is reasonably common and well-regarded. I won't go into a full explanation of how to use the framework, just show some example tests with it. You should be able to adapt, easily enough, a different framework to build similar tests.

Here is a simple test for the shortfall calculation:

```
describe('province', function() {
  it('shortfall', function() {
    const asia = new Province(sampleProvinceData());
    assert.equal(asia.shortfall, 5);
  });
});
```

The Mocha framework divides up the test code into blocks, each grouping together a suite of tests. Each test appears in an `it` block. For this simple case, the test has two steps. The first step sets up some fixture—data and objects that are needed for the test: in this case, a loaded province object. The second line verifies some characteristic of that fixture—in this case, that the shortfall is the amount that should be expected given the initial data.

Different developers use the descriptive strings in the `describe` and `it` blocks differently. Some would write a sentence that explains what the test is testing, but others prefer to leave them empty, arguing that the descriptive sentence is just duplicating the code in the same way a comment does. I like to put in just enough to identify which test is which when I get failures.

If I run this test in a NodeJS console, the output looks like this:

```
.....
1 passing (61ms)
```

Note the simplicity of the feedback—just a summary of how many tests are run and how many have passed.

When I write a test against existing code like this, it's nice to see that all is well—but I'm naturally skeptical. Particularly, once I have a lot of tests running, I'm always nervous that a test isn't really exercising the code the way I think it is, and thus won't catch a bug when I need it to. So I like to see every test fail at least once when I write it. My favorite way of doing that is to temporarily inject a fault into the code, for example:

Always make sure a test will fail when it should.



```
class Province...
  get shortfall() {
    return this._demand - this.totalProduction * 2;
  }
}
```

Here's what the console now looks like:

```

!

0 passing (72ms)
1 failing

1) province shortfall:
   AssertionError: expected -20 to equal 5
       at Context.<anonymous> (src/tester.js:10:12)

```

The framework indicates which test failed and gives some information about the nature of the failure—in this case, what value was expected and what value actually turned up. I therefore notice at once that something failed—and I can immediately see which tests failed, giving me a clue as to what went wrong (and, in this case, confirming the failure was where I injected it).



Run tests frequently. Run those exercising the code you're working on at least every few minutes; run all tests at least daily.

In a real system, I might have thousands of tests. A good test framework allows me to run them easily and to quickly see if any have failed. This simple feedback is essential to self-testing code. When I work, I'll be running tests very frequently—checking progress with new code or checking for mistakes with refactoring.

The Mocha framework can use different libraries, which it calls assertion libraries, to verify the fixture for a test. Being JavaScript, there are a quadzillion of them out there, some of which may still be current when you're reading this. The one I'm using at the moment is Chai [chai]. Chai allows me to write my validations either using an “assert” style:

```

describe('province', function() {
  it('shortfall', function() {
    const asia = new Province(sampleProvinceData());
    assert.equal(asia.shortfall, 5);
  });
});

```

or an “expect” style:

```

describe('province', function() {
  it('shortfall', function() {
    const asia = new Province(sampleProvinceData());
    expect(asia.shortfall).equal(5);
  });
});

```

I usually prefer the assert style, but at the moment I mostly use the expect style while working in JavaScript.

Different environments provide different ways to run tests. When I'm programming in Java, I use an IDE that gives me a graphical test runner. Its progress bar

is green as long as all the tests pass, and turns red should any of them fail. My colleagues often use the phrases “green bar” and “red bar” to describe the state of tests. I might say, “Never refactor on a red bar,” meaning you shouldn’t be refactoring if your test suite has a failing test. Or, I might say, “Revert to green” to say you should undo recent changes and go back to the last state where you had all-passing test suite (usually by going back to a recent version-control checkpoint).

Graphical test runners are nice, but not essential. I usually have my tests set to run from a single key in Emacs, and observe the text feedback in my compilation window. The key point is that I can quickly see if my tests are all OK.

Add Another Test

Now I’ll continue adding more tests. The style I follow is to look at all the things the class should do and test each one of them for any conditions that might cause the class to fail. This is not the same as testing every public method, which is what some programmers advocate. Testing should be risk-driven; remember, I’m trying to find bugs, now or in the future. Therefore I don’t test accessors that just read and write a field: They are so simple that I’m not likely to find a bug there.

This is important because trying to write too many tests usually leads to not writing enough. I get many benefits from testing even if I do only a little testing. My focus is to test the areas that I’m most worried about going wrong. That way I get the most benefit for my testing effort.

So I’ll start by hitting the other main output for this code—the profit calculation. Again, I’ll just do a basic test for profit on my initial fixture.

It is better to write and run incomplete tests than not to run complete tests.



```
describe('province', function() {
  it('shortfall', function() {
    const asia = new Province(sampleProvinceData());
    expect(asia.shortfall).equal(5);
  });
  it('profit', function() {
    const asia = new Province(sampleProvinceData());
    expect(asia.profit).equal(230);
  });
});
```

That shows the final result, but the way I got it was by first setting the expected value to a placeholder, then replacing it with whatever the program produced (230). I could have calculated it by hand myself, but since the code is supposed to be working correctly, I’ll just trust it for now. Once I have that new test working

correctly, I break it by altering the profit calculation with a spurious `* 2`. I satisfy myself that the test fails as it should, then revert my injected fault. This pattern—write with a placeholder for the expected value, replace the placeholder with the code’s actual value, inject a fault, revert the fault—is a common one I use when adding tests to existing code.

There is some duplication between these tests—both of them set up the fixture with the same first line. Just as I’m suspicious of duplicated code in regular code, I’m suspicious of it in test code, so will look to remove it by factoring to a common place. One option is to raise the constant to the outer scope.

```
describe('province', function() {  
  const asia = new Province(sampleProvinceData()); // DON'T DO THIS  
  it('shortfall', function() {  
    expect(asia.shortfall).equal(5);  
  });  
  it('profit', function() {  
    expect(asia.profit).equal(230);  
  });  
});
```

But as the comment indicates, I never do this. It will work for the moment, but it introduces a petri dish that’s primed for one of the nastiest bugs in testing—a shared fixture which causes tests to interact. The `const` keyword in JavaScript only means the reference to `asia` is constant, not the content of that object. Should a future test change that common object, I’ll end up with intermittent test failures due to tests interacting through the shared fixture, yielding different results depending on what order the tests are run in. That’s a nondeterminism in the tests that can lead to long and difficult debugging at best, and a collapse of confidence in the tests at worst. Instead, I prefer to do this:

```
describe('province', function() {  
  let asia;  
  beforeEach(function() {  
    asia = new Province(sampleProvinceData());  
  });  
  it('shortfall', function() {  
    expect(asia.shortfall).equal(5);  
  });  
  it('profit', function() {  
    expect(asia.profit).equal(230);  
  });  
});
```

The `beforeEach` clause is run before each test runs, clearing out `asia` and setting it to a fresh value each time. This way I build a fresh fixture before each test is run, which keeps the tests isolated and prevents the nondeterminism that causes so much trouble.

When I give this advice, some people are concerned that building a fresh fixture every time will slow down the tests. Most of the time, it won’t be noticeable. If

it is a problem, I'd consider a shared fixture, but then I will need to be really careful that no test ever changes it. I can also use a shared fixture if I'm sure it is truly immutable. But my reflex is to use a fresh fixture because the debugging cost of making a mistake with a shared fixture has bit me too often in the past.

Given I run the setup code in `beforeEach` with every test, why not leave the setup code inside the individual `it` blocks? I like my tests to all operate on a common bit of fixture, so I can become familiar with that standard fixture and see the various characteristics to test on it. The presence of the `beforeEach` block signals to the reader that I'm using a standard fixture. You can then look at all the tests within the scope of that describe block and know they all take the same base data as a starting point.

Modifying the Fixture

So far, the tests I've written show how I probe the properties of the fixture once I've loaded it. But in use, that fixture will be regularly updated by the users as they change values.

Most of the updates are simple setters, and I don't usually bother to test those as there's little chance they will be the source of a bug. But there is some complicated behavior around Producer's production setter, so I think that's worth a test.

describe('province'...

```
  it('change production', function() {
    asia.producers[0].production = 20;
    expect(asia.shortfall).equal(-6);
    expect(asia.profit).equal(292);
  });
```

This is a common pattern. I take the initial standard fixture that's **set up** by the `beforeEach` block, I **exercise** that fixture for the test, then I **verify** the fixture has done what I think it should have done. If you read much about testing, you'll hear these phases described variously as `setup-exercise-verify`, `given-when-then`, or `arrange-act-assert`. Sometimes you'll see all the steps present within the test itself, in other cases the common early phases can be pushed out into standard setup routines such as `beforeEach`.

(There is an implicit fourth phase that's usually not mentioned: **teardown**. Teardown removes the fixture between tests so that different tests don't interact with each other. By doing all my setup in `beforeEach`, I allow the test framework to implicitly tear down my fixture between tests, so I can take the teardown phase for granted. Most writers on tests gloss over teardown—reasonably so, since most of the time we ignore it. But occasionally, it can be important to have an explicit teardown operation, particularly if we have a fixture that we have to share between tests because it's slow to create.)

In this test, I'm verifying two different characteristics in a single `it` clause. As a general rule, it's wise to have only a single `verify` statement in each `it` clause. This is because the test will fail on the first verification failure—which can often hide useful information when you're figuring out why a test is broken. In this case, I feel the two are closely enough connected that I'm happy to have them in the same test. Should I wish to separate them into separate `it` clauses, I can do that later.

Probing the Boundaries

So far my tests have focused on regular usage, often referred to as “happy path” conditions where everything is going OK and things are used as expected. But it's also good to throw tests at the boundaries of these conditions—to see what happens when things might go wrong.

Whenever I have a collection of something, such as producers in this example, I like to see what happens when it's empty.

```
describe('no producers', function() {
  let noProducers;
  beforeEach(function() {
    const data = {
      name: "No proudcers",
      producers: [],
      demand: 30,
      price: 20
    };
    noProducers = new Province(data);
  });
  it('shortfall', function() {
    expect(noProducers.shortfall).equal(30);
  });
  it('profit', function() {
    expect(noProducers.profit).equal(0);
  });
});
```

With numbers, zeros are good things to probe:

```
describe('province'...
  it('zero demand', function() {
    asia.demand = 0;
    expect(asia.shortfall).equal(-25);
    expect(asia.profit).equal(0);
  });
```

as are negatives:

describe('province'...

```
it('negative demand', function() {
  asia.demand = -1;
  expect(asia.shortfall).equal(-26);
  expect(asia.profit).equal(-10);
});
```

At this point, I may start to wonder if a negative demand resulting in a negative profit really makes any sense for the domain. Shouldn't the minimum demand be zero? In which case, perhaps, the setter should react differently to a negative argument—raising an error or setting the value to zero anyway. These are good questions to ask, and writing tests like this helps me think about how the code ought to react to boundary cases.

The setters take a string from the fields in the UI, which are constrained to only accept numbers—but they can still be blank, so I should have tests that ensure the code responds to the blanks the way I want it to.

Think of the boundary conditions under which things might go wrong and concentrate your tests there.



describe('province'...

```
it('empty string demand', function() {
  asia.demand = "";
  expect(asia.shortfall).NaN;
  expect(asia.profit).NaN;
});
```

Notice how I'm playing the part of an enemy to my code. I'm actively thinking about how I can break it. I find that state of mind to be both productive and fun. It indulges the mean-spirited part of my psyche.

This one is interesting:

```
describe('string for producers', function() {
  it('', function() {
    const data = {
      name: "String producers",
      producers: "",
      demand: 30,
      price: 20
    };
    const prov = new Province(data);
    expect(prov.shortfall).equal(0);
  });
});
```

This doesn't produce a simple failure reporting that the shortfall isn't 0. Here's the console output:

```

.....!

9 passing (74ms)
1 failing

1) string for producers :
  TypeError: doc.producers.forEach is not a function
    at new Province (src/main.js:22:19)
    at Context.<anonymous> (src/tester.js:86:18)

```

Mocha treats this as a failure—but many testing frameworks distinguish between this situation, which they call an error, and a regular failure. A failure indicates a verify step where the actual value is outside the bounds expected by the verify statement. But this **error** is a different animal—it’s an exception raised during an earlier phase (in this case, the setup). This looks like an exception that the authors of the code hadn’t anticipated, so we get an error sadly familiar to JavaScript programmers (“... is not a function”).

How should the code respond to such a case? One approach is to add some handling that would give a better error response—either raising a more meaningful error message, or just setting `producers` to an empty array (with perhaps a log message). But there may also be valid reasons to leave it as it is. Perhaps the input object is produced by a trusted source—such as another part of the same code base. Putting in lots of validation checks between modules in the same code base can result in duplicate checks that cause more trouble than they are worth, especially if they duplicate validation done elsewhere. But if that input object is coming in from an external source, such as a JSON-encoded request, then validation checks are needed, and should be tested. In either case, writing tests like this raises these kinds of questions.

If I’m writing tests like this before refactoring, I would probably discard this test. Refactoring should preserve observable behavior; an error like this is outside the bounds of observable, so I need not be concerned if my refactoring changes the code’s response to this condition.

If this error could lead to bad data running around the program, causing a failure that will be hard to debug, I might use *Introduce Assertion (302)* to fail fast. I don’t add tests to catch such assertion failures, as they are themselves a form of test.



Don’t let the fear that testing can’t catch all bugs stop you from writing tests that catch most bugs.

When do you stop? I’m sure you have heard many times that you cannot prove that a program has no bugs by testing. That’s true, but it does not affect the ability of testing to speed up programming. I’ve seen various proposed rules to ensure you have tested every combination of everything. It’s worth taking a

look at these—but don’t let them get to you. There is a law of diminishing returns in testing, and there is the danger that by trying to write too many tests you

become discouraged and end up not writing any. You should concentrate on where the risk is. Look at the code and see where it becomes complex. Look at a function and consider the likely areas of error. Your tests will not find every bug, but as you refactor, you will understand the program better and thus find more bugs. Although I always start refactoring with a test suite, I invariably add to it as I go along.

Much More Than This

That's as far as I'm going to go with this chapter—after all, this is a book on refactoring, not on testing. But testing is an important topic, both because it's a necessary foundation for refactoring and because it's a valuable tool in its own right. While I've been happy to see the growth of refactoring as a programming practice since I wrote this book, I've been even happier to see the change in attitudes to testing. Previously seen as the responsibility of a separate (and inferior) group, testing is now increasingly a first-class concern of any decent software developer. Architectures often are, rightly, judged on their testability.

The kinds of tests I've shown here are unit tests, designed to operate on a small area of the code and run fast. They are the backbone of self-testing code; most tests in such a system are unit tests. There are other kinds of tests too, focusing on integration between components, exercising multiple levels of the software together, looking for performance issues, etc. (And even more varied than the types of tests are the arguments people get into about how to classify tests.)

Like most aspects of programming, testing is an iterative activity. Unless you are either very skilled or very lucky, you won't get your tests right the first time. I find I'm constantly working on the test suite—just as much as I work on the main code. Naturally, this means adding new tests as I add new features, but it also involves looking at the existing tests. Are they clear enough? Do I need to refactor them so I can more easily understand what they are doing? Have I got the right tests? An important habit to get into is to respond to a bug by first writing a test that clearly reveals the bug. Only after I have the test do I fix the bug. By having the test, I know the bug will stay dead. I also think about that bug and its test: Does it give me clues to other gaps in the test suite?

A common question is, "How much testing is enough?" There's no good measurement for this. Some people advocate using test coverage [mf-tc] as a measure, but test coverage analysis is only good for identifying untested areas of the code, not for assessing the quality of a test suite.

When you get a bug report, start by writing a unit test that exposes the bug.



The best measure for a good enough test suite is subjective: How confident are you that if someone introduces a defect into the code, some test will fail? This isn't something that can be objectively analyzed, and it doesn't account for false confidence, but the aim of self-testing code is to get that confidence. If I can refactor my code and be pretty sure that I've not introduced a bug because my tests come back green—then I can be happy that I have good enough tests.

It is possible to write too many tests. One sign of that is when I spend more time changing the tests than the code under test—and I feel the tests are slowing me down. But while over-testing does happen, it's vanishingly rare compared to under-testing.

Chapter 5

Introducing the Catalog

The rest of this book is a catalog of refactorings. This catalog started from my personal notes that I made to remind myself how to do refactorings in a safe and efficient way. Since then, I've refined the catalog, and there's more of it that comes from deliberate exploration of some refactoring moves. It's still something I use when I do a refactoring I haven't done in a while.

Format of the Refactorings

As I describe the refactorings in the catalog, I use a standard format. Each refactoring has five parts, as follows:

- I begin with a **name**. The name is important to building a vocabulary of refactorings. This is the name I use elsewhere in the book. Refactorings often go by different names now, so I also list any aliases that seem to be common.
- I follow the name with a short **sketch** of the refactoring. This helps you find a refactoring more quickly.
- The **motivation** describes why the refactoring should be done and describes circumstances in which it shouldn't be done.
- The **mechanics** are a concise, step-by-step description of how to carry out the refactoring.
- The **examples** show a very simple use of the refactoring to illustrate how it works.

The sketch shows a code example of the transformation of the refactoring. It's not meant to explain what the refactoring is, let alone how to do it, but it should remind you what the refactoring is if you've come across it before. If not, you'll probably need to work through the example to get a better idea. I also include

a small graphic; again, I don't intend it to be explanatory—it's more of a graphic memory-jogger.

The mechanics come from my own notes to remember how to do the refactoring when I haven't done it for a while. As such, they are somewhat terse, usually without explanations of why the steps are done that way. I give a more expansive explanation in the example. This way, the mechanics are short notes you can refer to easily when you know the refactoring but need to look up the steps (at least this is how I use them). You'll probably need to read the examples when you first do the refactoring.

I've written the mechanics in such a way that each step of each refactoring is as small as possible. I emphasize the safe way of doing the refactoring—which is to take very small steps and test after every one. At work, I usually take larger steps than some of the baby steps described, but if I run into a bug, I back out the last step and take the smaller steps. The steps include a number of references to special cases. The steps thus also function as a checklist; I often forget these things myself.

Although I (with few exceptions) only list one set of mechanics, they aren't the only way to carry out the refactoring. I selected the mechanics in the book because they work pretty well most of the time. It's likely you'll vary them as you get more practice in refactoring, and that's fine. Just remember that the key is to take small steps—and the trickier the situation, the smaller the steps.

The examples are of the laughably simple textbook kind. My aim with the examples is to help explain the basic refactoring with minimal distractions, so I hope you'll forgive the simplicity. (They are certainly not examples of good business modeling.) I'm sure you'll be able to apply them to your rather more complex situations. Some very simple refactorings don't have examples because I didn't think an example would add much.

In particular, remember that the examples are included only to illustrate the one refactoring under discussion. In most cases, there are still problems with the code at the end—but fixing these problems requires other refactorings. In a few cases in which refactorings often go together, I carry examples from one refactoring to another. In most cases, I leave the code as it is after the single refactoring. I do this to make each refactoring self-contained, because the primary role of the catalog is to be a reference.

I use color to highlight changed code where it may be difficult to spot among code that has not been changed. I do not use highlighting for all changed code, because too much defeats the purpose.

The Choice of Refactorings

This is by no means a complete catalog of refactorings. It is, I hope, a collection of those most useful to have them written down. By “most useful” I mean those

that are both commonly used and worthwhile to name and describe. I find something worthwhile to describe for a combination of reasons: Some have interesting mechanics which help general refactoring skills, some have a strong effect on improving the design of code.

Some refactorings are missing because they are so small and straightforward that I don't feel they are worth writing up. An example in the first edition was *Slide Statements (223)*—which I use frequently but didn't recognize as something I should include in the catalog (obviously, I changed my mind for this edition). These may well get added to the book over time, depending on how much energy I devote to new refactorings in the future.

Another category is refactorings that logically exist, but either aren't used much by me or show a simple similarity to other refactorings. Every refactoring in this book has a logical inverse refactoring, but I didn't write all of them up because I don't find many inverses interesting. *Encapsulate Variable (132)* is a common and powerful refactoring but its inverse is something I hardly ever do (and it is easy to perform anyway) so I didn't think we need a catalog entry for it.

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Chapter 6

A First Set of Refactorings

I'm starting the catalog with a set of refactorings that I consider the most useful to learn first.

Probably the most common refactoring I do is extracting code into a function (*Extract Function* (106)) or a variable (*Extract Variable* (119)). Since refactoring is all about change, it's no surprise that I also frequently use the inverses of those two (*Inline Function* (115) and *Inline Variable* (123)).

Extraction is all about giving names, and I often need to change the names as I learn. *Change Function Declaration* (124) changes names of functions; I also use that refactoring to add or remove a function's arguments. For variables, I use *Rename Variable* (137), which relies on *Encapsulate Variable* (132). When changing function arguments, I often find it useful to combine a common clump of arguments into a single object with *Introduce Parameter Object* (140).

Forming and naming functions are essential low-level refactorings—but, once created, it's necessary to group functions into higher-level modules. I use *Combine Functions into Class* (144) to group functions, together with the data they operate on, into a class. Another path I take is to combine them into a transform (*Combine Functions into Transform* (149)), which is particularly handy with read-only data. At a step further in scale, I can often form these modules into distinct processing phases using *Split Phase* (154).

Extract Function

formerly: *Extract Method*

inverse of: *Inline Function* (115)



```
function printOwing(invoice) {  
  printBanner();  
  let outstanding = calculateOutstanding();  
  
  //print details  
  console.log(`name: ${invoice.customer}`);  
  console.log(`amount: ${outstanding}`);  
}
```



```
function printOwing(invoice) {  
  printBanner();  
  let outstanding = calculateOutstanding();  
  printDetails(outstanding);  
  
  function printDetails(outstanding) {  
    console.log(`name: ${invoice.customer}`);  
    console.log(`amount: ${outstanding}`);  
  }  
}
```

Motivation

Extract Function is one of the most common refactorings I do. (Here, I use the term “function” but the same is true for a method in an object-oriented language, or any kind of procedure or subroutine.) I look at a fragment of code, understand what it is doing, then extract it into its own function named after its purpose.

During my career, I’ve heard many arguments about when to enclose code in its own function. Some of these guidelines were based on length: Functions should be no larger than fit on a screen. Some were based on reuse: Any code

used more than once should be put in its own function, but code only used once should be left inline. The argument that makes most sense to me, however, is the separation between intention and implementation. If you have to spend effort looking at a fragment of code and figuring out *what* it's doing, then you should extract it into a function and name the function after the "what." Then, when you read it again, the purpose of the function leaps right out at you, and most of the time you won't need to care about how the function fulfills its purpose (which is the body of the function).

Once I accepted this principle, I developed a habit of writing very small functions—typically, only a few lines long. To me, any function with more than half-a-dozen lines of code starts to smell, and it's not unusual for me to have functions that are a single line of code. The fact that size isn't important was brought home to me by an example that Kent Beck showed me from the original Smalltalk system. Smalltalk in those days ran on black-and-white systems. If you wanted to highlight some text or graphics, you would reverse the video. Smalltalk's graphics class had a method for this called `highlight`, whose implementation was just a call to the method `reverse`. The name of the method was longer than its implementation—but that didn't matter because there was a big distance between the intention of the code and its implementation.

Some people are concerned about short functions because they worry about the performance cost of a function call. When I was young, that was occasionally a factor, but that's very rare now. Optimizing compilers often work better with shorter functions which can be cached more easily. As always, follow the general guidelines on performance optimization.

Small functions like this only work if the names are good, so you need to pay good attention to naming. This takes practice—but once you get good at it, this approach can make code remarkably self-documenting.

Often, I see fragments of code in a larger function that start with a comment to say what they do. The comment is often a good hint for the name of the function when I extract that fragment.

Mechanics

- Create a new function, and name it after the intent of the function (name it by what it does, not by how it does it).

If the code I want to extract is very simple, such as a single function call, I still extract it if the name of the new function will reveal the intent of the code in a better way. If I can't come up with a more meaningful name, that's a sign that I shouldn't extract the code. However, I don't have to come up with the best name right away; sometimes a good name only appears as I work with the extraction. It's OK to extract a function, try to work with it, realize it isn't helping, and then inline it back again. As long as I've learned something, my time wasn't wasted.

If the language supports nested functions, nest the extracted function inside the source function. That will reduce the amount of out-of-scope variables to deal with after the next couple of steps. I can always use *Move Function (198)* later.

- Copy the extracted code from the source function into the new target function.
- Scan the extracted code for references to any variables that are local in scope to the source function and will not be in scope for the extracted function. Pass them as parameters.

If I extract into a nested function of the source function, I don't run into these problems.

Usually, these are local variables and parameters to the function. The most general approach is to pass all such parameters in as arguments. There are usually no difficulties for variables that are used but not assigned to.

If a variable is only used inside the extracted code but is declared outside, move the declaration into the extracted code.

Any variables that are assigned to need more care if they are passed by value. If there's only one of them, I try to treat the extracted code as a query and assign the result to the variable concerned.

Sometimes, I find that too many local variables are being assigned by the extracted code. It's better to abandon the extraction at this point. When this happens, I consider other refactorings such as *Split Variable (240)* or *Replace Temp with Query (178)* to simplify variable usage and revisit the extraction later.

- Compile after all variables are dealt with.

Once all the variables are dealt with, it can be useful to compile if the language environment does compile-time checks. Often, this will help find any variables that haven't been dealt with properly.

- Replace the extracted code in the source function with a call to the target function.
- Test.
- Look for other code that's the same or similar to the code just extracted, and consider using *Replace Inline Code with Function Call (222)* to call the new function.

Some refactoring tools support this directly. Otherwise, it can be worth doing some quick searches to see if duplicate code exists elsewhere.

Example: No Variables Out of Scope

In the simplest case, Extract Function is trivially easy.

```
function printOwing(invoice) {
  let outstanding = 0;

  console.log("*****");
  console.log("**** Customer Owes ****");
  console.log("*****");

  // calculate outstanding
  for (const o of invoice.orders) {
    outstanding += o.amount;
  }

  // record due date
  const today = Clock.today;
  invoice.dueDate = new Date(today.getFullYear(), today.getMonth(), today.getDate() + 30);

  //print details
  console.log(`name: ${invoice.customer}`);
  console.log(`amount: ${outstanding}`);
  console.log(`due: ${invoice.dueDate.toLocaleDateString()}`);
}
```

*You may be wondering what the `Clock.today` is about. It is a *Clock Wrapper* [mf-cw]—an object that wraps calls to the system clock. I avoid putting direct calls to things like `Date.now()` in my code, because it leads to nondeterministic tests and makes it difficult to reproduce error conditions when diagnosing failures.*

It's easy to extract the code that prints the banner. I just cut, paste, and put in a call:

```
function printOwing(invoice) {
  let outstanding = 0;

  printBanner();

  // calculate outstanding
  for (const o of invoice.orders) {
    outstanding += o.amount;
  }

  // record due date
  const today = Clock.today;
  invoice.dueDate = new Date(today.getFullYear(), today.getMonth(), today.getDate() + 30);
}
```

```

//print details
console.log(`name: ${invoice.customer}`);
console.log(`amount: ${outstanding}`);
console.log(`due: ${invoice.dueDate.toLocaleDateString()}`);
}
function printBanner() {
  console.log("*****");
  console.log("**** Customer Owes ****");
  console.log("*****");
}

```

Similarly, I can take the printing of details and extract that too:

```

function printOwing(invoice) {
  let outstanding = 0;

  printBanner();

  // calculate outstanding
  for (const o of invoice.orders) {
    outstanding += o.amount;
  }

  // record due date
  const today = Clock.today;
  invoice.dueDate = new Date(today.getFullYear(), today.getMonth(), today.getDate() + 30);

  printDetails();

  function printDetails() {
    console.log(`name: ${invoice.customer}`);
    console.log(`amount: ${outstanding}`);
    console.log(`due: ${invoice.dueDate.toLocaleDateString()}`);
  }
}

```

This makes Extract Function seem like a trivially easy refactoring. But in many situations, it turns out to be rather more tricky.

In the case above, I defined `printDetails` so it was nested inside `printOwing`. That way it was able to access all the variables defined in `printOwing`. But that's not an option to me if I'm programming in a language that doesn't allow nested functions. Then I'm faced, essentially, with the problem of extracting the function to the top level, which means I have to pay attention to any variables that exist only in the scope of the source function. These are the arguments to the original function and the temporary variables defined in the function.

Example: Using Local Variables

The easiest case with local variables is when they are used but not reassigned. In this case, I can just pass them in as parameters. So if I have the following function:

```
function printOwing(invoice) {
  let outstanding = 0;

  printBanner();

  // calculate outstanding
  for (const o of invoice.orders) {
    outstanding += o.amount;
  }

  // record due date
  const today = Clock.today;
  invoice.dueDate = new Date(today.getFullYear(), today.getMonth(), today.getDate() + 30);

  //print details
  console.log(`name: ${invoice.customer}`);
  console.log(`amount: ${outstanding}`);
  console.log(`due: ${invoice.dueDate.toLocaleDateString()}`);
}
```

I can extract the printing of details passing two parameters:

```
function printOwing(invoice) {
  let outstanding = 0;

  printBanner();

  // calculate outstanding
  for (const o of invoice.orders) {
    outstanding += o.amount;
  }

  // record due date
  const today = Clock.today;
  invoice.dueDate = new Date(today.getFullYear(), today.getMonth(), today.getDate() + 30);

  printDetails(invoice, outstanding);
}

function printDetails(invoice, outstanding) {
  console.log(`name: ${invoice.customer}`);
  console.log(`amount: ${outstanding}`);
  console.log(`due: ${invoice.dueDate.toLocaleDateString()}`);
}
```

The same is true if the local variable is a structure (such as an array, record, or object) and I modify that structure. So, I can similarly extract the setting of the due date:

```

function printOwing(invoice) {
  let outstanding = 0;

  printBanner();

  // calculate outstanding
  for (const o of invoice.orders) {
    outstanding += o.amount;
  }

  recordDueDate(invoice);
  printDetails(invoice, outstanding);
}
function recordDueDate(invoice) {
  const today = Clock.today;
  invoice.dueDate = new Date(today.getFullYear(), today.getMonth(), today.getDate() + 30);
}

```

Example: Reassigning a Local Variable

It's the assignment to local variables that becomes complicated. In this case, we're only talking about temps. If I see an assignment to a parameter, I immediately use *Split Variable* (240), which turns it into a temp.

For temps that are assigned to, there are two cases. The simpler case is where the variable is a temporary variable used only within the extracted code. When that happens, the variable just exists within the extracted code. Sometimes, particularly when variables are initialized at some distance before they are used, it's handy to use *Slide Statements* (223) to get all the variable manipulation together.

The more awkward case is where the variable is used outside the extracted function. In that case, I need to return the new value. I can illustrate this with the following familiar-looking function:

```

function printOwing(invoice) {
  let outstanding = 0;

  printBanner();

  // calculate outstanding
  for (const o of invoice.orders) {
    outstanding += o.amount;
  }

  recordDueDate(invoice);
  printDetails(invoice, outstanding);
}

```

I've shown the previous refactorings all in one step, since they were straightforward, but this time I'll take it one step at a time from the mechanics. First, I'll slide the declaration next to its use.

```
function printOwing(invoice) {  
  printBanner();  
  
  // calculate outstanding  
  let outstanding = 0;  
  for (const o of invoice.orders) {  
    outstanding += o.amount;  
  }  
  
  recordDueDate(invoice);  
  printDetails(invoice, outstanding);  
}
```

I then copy the code I want to extract into a target function.

```
function printOwing(invoice) {  
  printBanner();  
  
  // calculate outstanding  
  let outstanding = 0;  
  for (const o of invoice.orders) {  
    outstanding += o.amount;  
  }  
  
  recordDueDate(invoice);  
  printDetails(invoice, outstanding);  
}  
function calculateOutstanding(invoice) {  
  let outstanding = 0;  
  for (const o of invoice.orders) {  
    outstanding += o.amount;  
  }  
  return outstanding;  
}
```

Since I moved the declaration of `outstanding` into the extracted code, I don't need to pass it in as a parameter. The `outstanding` variable is the only one reassigned in the extracted code, so I can return it.

My JavaScript environment doesn't yield any value by compiling—indeed less than I'm getting from the syntax analysis in my editor—so there's no step to do here. My next thing to do is to replace the original code with a call to the new function. Since I'm returning the value, I need to store it in the original variable.

```
function printOwing(invoice) {
  printBanner();
  let outstanding = calculateOutstanding(invoice);
  recordDueDate(invoice);
  printDetails(invoice, outstanding);
}
function calculateOutstanding(invoice) {
  let outstanding = 0;
  for (const o of invoice.orders) {
    outstanding += o.amount;
  }
  return outstanding;
}
```

Before I consider myself done, I rename the return value to follow my usual coding style.

```
function printOwing(invoice) {
  printBanner();
  const outstanding = calculateOutstanding(invoice);
  recordDueDate(invoice);
  printDetails(invoice, outstanding);
}
function calculateOutstanding(invoice) {
  let result = 0;
  for (const o of invoice.orders) {
    result += o.amount;
  }
  return result;
}
```

I also take the opportunity to change the original `outstanding` into a `const`.

At this point you may be wondering, “What happens if more than one variable needs to be returned?”

Here, I have several options. Usually I prefer to pick different code to extract. I like a function to return one value, so I would try to arrange for multiple functions for the different values. If I really need to extract with multiple values, I can form a record and return that—but usually I find it better to rework the temporary variables instead. Here I like using *Replace Temp with Query* (178) and *Split Variable* (240).

This raises an interesting question when I’m extracting functions that I expect to then move to another context, such as top level. I prefer small steps, so my instinct is to extract into a nested function first, then move that nested function to its new context. But the tricky part of this is dealing with variables and I don’t expose that difficulty until I do the move. This argues that even though I can extract into a nested function, it makes sense to extract to at least the sibling level of the source function first, so I can immediately tell if the extracted code makes sense.

Inline Function

formerly: *Inline Method*

inverse of: *Extract Function* (106)



```
function getRating(driver) {  
  return moreThanFiveLateDeliveries(driver) ? 2 : 1;  
}  
  
function moreThanFiveLateDeliveries(driver) {  
  return driver.numberOfLateDeliveries > 5;  
}
```



```
function getRating(driver) {  
  return (driver.numberOfLateDeliveries > 5) ? 2 : 1;  
}
```

Motivation

One of the themes of this book is using short functions named to show their intent, because these functions lead to clearer and easier to read code. But sometimes, I do come across a function in which the body is as clear as the name. Or, I refactor the body of the code into something that is just as clear as the name. When this happens, I get rid of the function. Indirection can be helpful, but needless indirection is irritating.

I also use Inline Function is when I have a group of functions that seem badly factored. I can inline them all into one big function and then reextract the functions the way I prefer.

I commonly use Inline Function when I see code that's using too much indirection—when it seems that every function does simple delegation to another function, and I get lost in all the delegation. Some of this indirection may be worthwhile, but not all of it. By inlining, I can flush out the useful ones and eliminate the rest.

Mechanics

- Check that this isn't a polymorphic method.

If this is a method in a class, and has subclasses that override it, then I can't inline it.

- Find all the callers of the function.
- Replace each call with the function's body.
- Test after each replacement.

The entire inlining doesn't have to be done all at once. If some parts of the inline are tricky, they can be done gradually as opportunity permits.

- Remove the function definition.

Written this way, Inline Function is simple. In general, it isn't. I could write pages on how to handle recursion, multiple return points, inlining a method into another object when you don't have accessors, and the like. The reason I don't is that if you encounter these complexities, you shouldn't do this refactoring.

Example

In the simplest case, this refactoring is so easy it's trivial. I start with

```
function rating(aDriver) {  
  return moreThanFiveLateDeliveries(aDriver) ? 2 : 1;  
}  
function moreThanFiveLateDeliveries(aDriver) {  
  return aDriver.numberOfLateDeliveries > 5;  
}
```

I can just take the return expression of the called function and paste it into the caller to replace the call.

```
function rating(aDriver) {  
  return aDriver.numberOfLateDeliveries > 5 ? 2 : 1;  
}
```

But it can be a little more involved than that, requiring me to do more work to fit the code into its new home. Consider the case where I start with this slight variation on the earlier initial code.

```
function rating(aDriver) {
    return moreThanFiveLateDeliveries(aDriver) ? 2 : 1;
}

function moreThanFiveLateDeliveries(dvr) {
    return dvr.numberOfLateDeliveries > 5;
}
```

Almost the same, but now the declared argument on `moreThanFiveLateDeliveries` is different to the name of the passed-in argument. So I have to fit the code a little when I do the inline.

```
function rating(aDriver) {
    return aDriver.numberOfLateDeliveries > 5 ? 2 : 1;
}
```

It can be even more involved than this. Consider this code:

```
function reportLines(aCustomer) {
    const lines = [];
    gatherCustomerData(lines, aCustomer);
    return lines;
}

function gatherCustomerData(out, aCustomer) {
    out.push(["name", aCustomer.name]);
    out.push(["location", aCustomer.location]);
}
```

Inlining `gatherCustomerData` into `reportLines` isn't a simple cut and paste. It's not too complicated, and most times I would still do this in one go, with a bit of fitting. But to be cautious, it may make sense to move one line at a time. So I'd start with using *Move Statements to Callers* (217) on the first line (I'd do it the simple way with a cut, paste, and fit).

```
function reportLines(aCustomer) {
    const lines = [];
    lines.push(["name", aCustomer.name]);
    gatherCustomerData(lines, aCustomer);
    return lines;
}

function gatherCustomerData(out, aCustomer) {
    out.push(["name", aCustomer.name]);
    out.push(["location", aCustomer.location]);
}
```

I then continue with the other lines until I'm done.

```
function reportLines(aCustomer) {  
  const lines = [];  
  lines.push(["name", aCustomer.name]);  
  lines.push(["location", aCustomer.location]);  
  return lines;  
}
```

The point here is to always be ready to take smaller steps. Most of the time, with the small functions I normally write, I can do Inline Function in one go, even if there is a bit of refitting to do. But if I run into complications, I go one line at a time. Even with one line, things can get a bit awkward; then, I'll use the more elaborate mechanics for *Move Statements to Callers* (217) to break things down even more. And if, feeling confident, I do something the quick way and the tests break, I prefer to revert back to my last green code and repeat the refactoring with smaller steps and a touch of chagrin.

Extract Variable

formerly: *Introduce Explaining Variable*

inverse of: *Inline Variable* (123)



```
return order.quantity * order.itemPrice -  
    Math.max(0, order.quantity - 500) * order.itemPrice * 0.05 +  
    Math.min(order.quantity * order.itemPrice * 0.1, 100);
```



```
const basePrice = order.quantity * order.itemPrice;  
const quantityDiscount = Math.max(0, order.quantity - 500) * order.itemPrice * 0.05;  
const shipping = Math.min(basePrice * 0.1, 100);  
return basePrice - quantityDiscount + shipping;
```

Motivation

Expressions can become very complex and hard to read. In such situations, local variables may help break the expression down into something more manageable. In particular, they give me an ability to name a part of a more complex piece of logic. This allows me to better understand the purpose of what's happening.

Such variables are also handy for debugging, since they provide an easy hook for a debugger or print statement to capture.

If I'm considering Extract Variable, it means I want to add a name to an expression in my code. Once I've decided I want to do that, I also think about the context of that name. If it's only meaningful within the function I'm working on, then Extract Variable is a good choice—but if it makes sense in a broader context, I'll consider making the name available in that broader context, usually as a function. If the name is available more widely, then other code can use that expression without having to repeat the expression, leading to less duplication and a better statement of my intent.

The downside of promoting the name to a broader context is extra effort. If it's significantly more effort, I'm likely to leave it till later when I can use *Replace Temp with Query* (178). But if it's easy, I like to do it now so the name is immediately available in the code. As a good example of this, if I'm working in a class, then *Extract Function* (106) is very easy to do.

Mechanics

- Ensure that the expression you want to extract does not have side effects.
- Declare an immutable variable. Set it to a copy of the expression you want to name.
- Replace the original expression with the new variable.
- Test.

If the expression appears more than once, replace each occurrence with the variable, testing after each replacement.

Example

I start with a simple calculation

```
function price(order) {  
  //price is base price - quantity discount + shipping  
  return order.quantity * order.itemPrice -  
    Math.max(0, order.quantity - 500) * order.itemPrice * 0.05 +  
    Math.min(order.quantity * order.itemPrice * 0.1, 100);  
}
```

Simple as it may be, I can make it still easier to follow. First, I recognize that the base price is the multiple of the quantity and the item price.

```
function price(order) {  
  //price is base price - quantity discount + shipping  
  return order.quantity * order.itemPrice -  
    Math.max(0, order.quantity - 500) * order.itemPrice * 0.05 +  
    Math.min(order.quantity * order.itemPrice * 0.1, 100);  
}
```

Once that understanding is in my head, I put it in the code by creating and naming a variable for it.

```
function price(order) {  
  //price is base price - quantity discount + shipping  
  const basePrice = order.quantity * order.itemPrice;  
  return order.quantity * order.itemPrice -  
    Math.max(0, order.quantity - 500) * order.itemPrice * 0.05 +  
    Math.min(order.quantity * order.itemPrice * 0.1, 100);  
}
```

Of course, just declaring and initializing a variable doesn't do anything; I also have to use it, so I replace the expression that I used as its source.

```
function price(order) {
  //price is base price - quantity discount + shipping
  const basePrice = order.quantity * order.itemPrice;
  return basePrice -
    Math.max(0, order.quantity - 500) * order.itemPrice * 0.05 +
    Math.min(order.quantity * order.itemPrice * 0.1, 100);
}
```

That same expression is used later on, so I can replace it with the variable there too.

```
function price(order) {
  //price is base price - quantity discount + shipping
  const basePrice = order.quantity * order.itemPrice;
  return basePrice -
    Math.max(0, order.quantity - 500) * order.itemPrice * 0.05 +
    Math.min(basePrice * 0.1, 100);
}
```

The next line is the quantity discount, so I can extract that too.

```
function price(order) {
  //price is base price - quantity discount + shipping
  const basePrice = order.quantity * order.itemPrice;
  const quantityDiscount = Math.max(0, order.quantity - 500) * order.itemPrice * 0.05;
  return basePrice -
    quantityDiscount +
    Math.min(basePrice * 0.1, 100);
}
```

Finally, I finish with the shipping. As I do that, I can remove the comment, too, because it no longer says anything the code doesn't say.

```
function price(order) {
  const basePrice = order.quantity * order.itemPrice;
  const quantityDiscount = Math.max(0, order.quantity - 500) * order.itemPrice * 0.05;
  const shipping = Math.min(basePrice * 0.1, 100);
  return basePrice - quantityDiscount + shipping;
}
```

Example: With a Class

Here's the same code, but this time in the context of a class:

```
class Order {
  constructor(aRecord) {
    this._data = aRecord;
  }
}
```

```
get quantity() {return this._data.quantity;}
get itemPrice() {return this._data.itemPrice;}

get price() {
    return this.quantity * this.itemPrice -
        Math.max(0, this.quantity - 500) * this.itemPrice * 0.05 +
        Math.min(this.quantity * this.itemPrice * 0.1, 100);
}
```

In this case, I want to extract the same names, but I realize that the names apply to the `Order` as a whole, not just the calculation of the price. Since they apply to the whole order, I'm inclined to extract the names as methods rather than variables.

```
class Order {
    constructor(aRecord) {
        this._data = aRecord;
    }
    get quantity() {return this._data.quantity;}
    get itemPrice() {return this._data.itemPrice;}

    get price() {
        return this.basePrice - this.quantityDiscount + this.shipping;
    }
    get basePrice() {return this.quantity * this.itemPrice;}
    get quantityDiscount() {return Math.max(0, this.quantity - 500) * this.itemPrice * 0.05;}
    get shipping() {return Math.min(this.basePrice * 0.1, 100);}
}
```

This is one of the great benefits of objects—they give you a reasonable amount of context for logic to share other bits of logic and data. For something as simple as this, it doesn't matter so much, but with a larger class it becomes very useful to call out common hunks of behavior as their own abstractions with their own names to refer to them whenever I'm working with the object.

Inline Variable

formerly: *Inline Temp*

inverse of: *Extract Variable* (119)



```
let basePrice = anOrder.basePrice;  
return (basePrice > 1000);
```



```
return anOrder.basePrice > 1000;
```

Motivation

Variables provide names for expressions within a function, and as such they are usually a Good Thing. But sometimes, the name doesn't really communicate more than the expression itself. At other times, you may find that a variable gets in the way of refactoring the neighboring code. In these cases, it can be useful to inline the variable.

Mechanics

- Check that the right-hand side of the assignment is free of side effects.
- If the variable isn't already declared immutable, do so and test.
 - This checks that it's only assigned to once.
- Find the first reference to the variable and replace it with the right-hand side of the assignment.
- Test.
- Repeat replacing references to the variable until you've replaced all of them.
- Remove the declaration and assignment of the variable.
- Test.

Change Function Declaration

aka: *Rename Function*

formerly: *Rename Method*

formerly: *Add Parameter*

formerly: *Remove Parameter*

aka: *Change Signature*



```
function circum(radius) {...}
```



```
function circumference(radius) {...}
```

Motivation

Functions represent the primary way we break a program down into parts. Function declarations represent how these parts fit together—effectively, they represent the joints in our software systems. And, as with any construction, much depends on those joints. Good joints allow me to add new parts to the system easily, but bad ones are a constant source of difficulty, making it harder to figure out what the software does and how to modify it as my needs change. Fortunately, software, being soft, allows me to change these joints, providing I do it carefully.

The most important element of such a joint is the name of the function. A good name allows me to understand what the function does when I see it called, without seeing the code that defines its implementation. However, coming up with good names is hard, and I rarely get my names right the first time. When I find a name that's confused me, I'm tempted to leave it—after all, it's only a name. This is the work of the evil demon *Obfuscatis*; for the sake of my program's soul I must never listen to him. If I see a function with the wrong name, it is imperative that I change it as soon as I understand what a better name could be. That way,

the next time I'm looking at this code, I don't have to figure out *again* what's going on. (Often, a good way to improve a name is to write a comment to describe the function's purpose, then turn that comment into a name.)

Similar logic applies to a function's parameters. The parameters of a function dictate how a function fits in with the rest of its world. Parameters set the context in which I can use a function. If I have a function to format a person's telephone number, and that function takes a person as its argument, then I can't use it to format a company's telephone number. If I replace the person parameter with the telephone number itself, then the formatting code is more widely useful.

Apart from increasing a function's range of applicability, I can also remove some coupling, changing what modules need to connect to others. Telephone formatting logic may sit in a module that has no knowledge about people. Reducing how much modules need to know about each other helps reduce how much I need to put into my brain when I change something—and my brain isn't as big as it used to be (that doesn't say anything about the size of its container, though).

Choosing the right parameters isn't something that adheres to simple rules. I may have a simple function for determining if a payment is overdue, by looking at if it's older than 30 days. Should the parameter to this function be the payment object, or the due date of the payment? Using the payment couples the function to the interface of the payment object. But if I use the payment, I can easily access other properties of the payment, should the logic evolve, without having to change every bit of code that calls this function—essentially, increasing the encapsulation of the function.

The only right answer to this puzzle is that there is no right answer, especially over time. So I find it's essential to be familiar with Change Function Declaration so the code can evolve with my understanding of what the best joints in the code need to be.

Usually, I only use the main name of a refactoring when I refer to it from elsewhere in this book. However, since renaming is such a significant use case for Change Function Declaration, if I'm just renaming something, I'll refer to this refactoring as *Rename Function* to make it clearer what I'm doing. Whether I'm merely renaming or manipulating the parameters, I use the same mechanics.

Mechanics

In most of the refactorings in this book, I present only a single set of mechanics. This isn't because there is only one set that will do the job but because, usually, one set of mechanics will work reasonably well for most cases. Change Function Declaration, however, is an exception. The simple mechanics are often effective, but there are plenty of cases when a more gradual migration makes more sense. So, with this refactoring, I look at the change and ask myself if I think I can change the declaration and all its callers easily in one go. If so, I follow the simple mechanics. The migration-style mechanics allow me to change the callers more gradually—which is important if I have lots of them, they are awkward to get

to, the function is a polymorphic method, or I have a more complicated change to the declaration.

Simple Mechanics

- If you're removing a parameter, ensure it isn't referenced in the body of the function.
- Change the method declaration to the desired declaration.
- Find all references to the old method declaration, update them to the new one.
- Test.

It's often best to separate changes, so if you want to both change the name and add a parameter, do these as separate steps. (In any case, if you run into trouble, revert and use the migration mechanics instead.)

Migration Mechanics

- If necessary, refactor the body of the function to make it easy to do the following extraction step.
- Use *Extract Function (106)* on the function body to create the new function.
If the new function will have the same name as the old one, give the new function a temporary name that's easy to search for.
- If the extracted function needs additional parameters, use the simple mechanics to add them.
- Test.
- Apply *Inline Function (115)* to the old function.
- If you used a temporary name, use *Change Function Declaration (124)* again to restore it to the original name.
- Test.

If you're changing a method on a class with polymorphism, you'll need to add indirection for each binding. If the method is polymorphic within a single class hierarchy, you only need the forwarding method on the superclass. If the polymorphism has no superclass link, then you'll need forwarding methods on each implementation class.

If you are refactoring a published API, you can pause the refactoring once you've created the new function. During this pause, deprecate the original function and wait for clients to change to the new function. The original function declara-

tion can be removed when (and if) you're confident all the clients of the old function have migrated to the new one.

Example: Renaming a Function (Simple Mechanics)

Consider this function with an overly abbreviated name:

```
function circum(radius) {  
    return 2 * Math.PI * radius;  
}
```

I want to change that to something more sensible. I begin by changing the declaration:

```
function circumference(radius) {  
    return 2 * Math.PI * radius;  
}
```

I then find all the callers of `circum` and change the name to `circumference`.

Different language environments have an impact on how easy it is to find all the references to the old function. Static typing and a good IDE provide the best experience, usually allowing me to rename functions automatically with little chance of error. Without static typing, this can be more involved; even good searching tools will then have a lot of false positives.

I use the same approach for adding or removing parameters: find all the callers, change the declaration, and change the callers. It's often better to do these as separate steps—so, if I'm both renaming the function and adding a parameter, I first do the rename, test, then add the parameter, and test again.

A disadvantage of this simple way of doing the refactoring is that I have to do all the callers and the declaration (or all of them, if polymorphic) at once. If there are only a few of them, or if I have decent automated refactoring tools, this is reasonable. But if there's a lot, it can get tricky. Another problem is when the names aren't unique—e.g., I want to rename the `changeAddress` method on a `person` class but the same method, which I don't want to change, exists on an `insurance agreement` class. The more complex the change is, the less I want to do it in one go like this. When this kind of problem arises, I use the migration mechanics instead. Similarly, if I use simple mechanics and something goes wrong, I'll revert the code to the last known good state and try again using migration mechanics.

Example: Renaming a Function (Migration Mechanics)

Again, I have this function with its overly abbreviated name:

```
function circum(radius) {  
    return 2 * Math.PI * radius;  
}
```

To do this refactoring with migration mechanics, I begin by applying *Extract Function (106)* to the entire function body.

```
function circum(radius) {  
  return circumference(radius);  
}  
function circumference(radius) {  
  return 2 * Math.PI * radius;  
}
```

I test that, then apply *Inline Function (115)* to the old functions. I find all the calls of the old function and replace each one with a call of the new one. I can test after each change, which allows me to do them one at a time. Once I've got them all, I remove the old function.

With most refactorings, I'm changing code that I can modify, but this refactoring can be handy with a published API—that is, one used by code that I'm unable to change myself. I can pause the refactoring after creating `circumference` and, if possible, mark `circum` as deprecated. I will then wait for callers to change to use `circumference`; once they do, I can delete `circum`. Even if I'm never able to reach the happy point of deleting `circum`, at least I have a better name for new code.

Example: Adding a Parameter

In some software, to manage a library of books, I have a book class which has the ability to take a reservation for a customer.

class Book...

```
addReservation(customer) {  
  this._reservations.push(customer);  
}
```

I need to support a priority queue for reservations. Thus, I need an extra parameter on `addReservation` to indicate whether the reservation should go in the usual queue or the high-priority queue. If I can easily find and change all the callers, then I can just go ahead with the change—but if not, I can use the migration approach, which I'll show here.

I begin by using *Extract Function (106)* on the body of `addReservation` to create the new function. Although it will eventually be called `addReservation`, the new and old functions can't coexist with the same name. So I use a temporary name that will be easy to search for later.

class Book...

```
addReservation(customer) {  
  this.zz_addReservation(customer);  
}
```

```

zz_addReservation(customer) {
  this._reservations.push(customer);
}

```

I then add the parameter to the new declaration and its call (in effect, using the simple mechanics).

```

class Book...
  addReservation(customer) {
    this.zz_addReservation(customer, false);
  }

  zz_addReservation(customer, isPriority) {
    this._reservations.push(customer);
  }

```

When I use JavaScript, before I change any of the callers, I like to apply *Introduce Assertion (302)* to check the new parameter is used by the caller.

```

class Book...
  zz_addReservation(customer, isPriority) {
    assert(isPriority === true || isPriority === false);
    this._reservations.push(customer);
  }

```

Now, when I change the callers, if I make a mistake and leave off the new parameter, this assertion will help me catch the mistake. And I know from long experience there are few more mistake-prone programmers than myself.

Now, I can start changing the callers by using *Inline Function (115)* on the original function. This allows me to change one caller at a time.

I then rename the new function back to the original. Usually, the simple mechanics work fine for this, but I can also use the migration approach if I need to.

Example: Changing a Parameter to One of Its Properties

The examples so far are simple changes of a name and adding a new parameter, but with the migration mechanics, this refactoring can handle more complicated cases quite neatly. Here's an example that is a bit more involved.

I have a function which determines if a customer is based in New England.

```

function inNewEngland(aCustomer) {
  return ["MA", "CT", "ME", "VT", "NH", "RI"].includes(aCustomer.address.state);
}

```

Here is one of its callers:

```

caller...
const newEnglanders = someCustomers.filter(c => inNewEngland(c));

```

`inNewEngland` only uses the customer's home state to determine if it's in New England. I'd prefer to refactor `inNewEngland` so that it takes a state code as a parameter, making it usable in more contexts by removing the dependency on the customer.

With Change Function Declaration, my usual first move is to apply *Extract Function* (106), but in this case I can make it easier by first refactoring the function body a little. I use *Extract Variable* (119) on my desired new parameter.

```
function inNewEngland(aCustomer) {
  const stateCode = aCustomer.address.state;
  return ["MA", "CT", "ME", "VT", "NH", "RI"].includes(stateCode);
}
```

Now I use *Extract Function* (106) to create that new function.

```
function inNewEngland(aCustomer) {
  const stateCode = aCustomer.address.state;
  return xxNEWinNewEngland(stateCode);
}

function xxNEWinNewEngland(stateCode) {
  return ["MA", "CT", "ME", "VT", "NH", "RI"].includes(stateCode);
}
```

I give the function a name that's easy to automatically replace to turn into the original name later. (You can tell I don't have a standard for these temporary names.)

I apply *Inline Variable* (123) on the input parameter in the original function.

```
function inNewEngland(aCustomer) {
  return xxNEWinNewEngland(aCustomer.address.state);
}
```

I use *Inline Function* (115) to fold the old function into its callers, effectively replacing the call to the old function with a call to the new one. I can do these one at a time.

caller...

```
const newEnglanders = someCustomers.filter(c => xxNEWinNewEngland(c.address.state));
```

Once I've inlined the old function into every caller, I use Change Function Declaration again to change the name of the new function to that of the original.

caller...

```
const newEnglanders = someCustomers.filter(c => inNewEngland(c.address.state));
```

top level...

```
function inNewEngland(stateCode) {
  return ["MA", "CT", "ME", "VT", "NH", "RI"].includes(stateCode);
}
```


Automated refactoring tools make the migration mechanics both less useful and more effective. They make it less useful because they handle even complicated renames and parameter changes safer, so I don't have to use the migration approach as often as I do without that support. However, in cases like this example, where the tools can't do the whole refactoring, they still make it much easier as the key moves of extract and inline can be done more quickly and safely with the tool.

Encapsulate Variable

formerly: *Self-Encapsulate Field*

formerly: *Encapsulate Field*



```
let defaultOwner = {firstName: "Martin", lastName: "Fowler"};
```



```
let defaultOwnerData = {firstName: "Martin", lastName: "Fowler"};
export function defaultOwner() {return defaultOwnerData;}
export function setDefaultOwner(arg) {defaultOwnerData = arg;}
```

Motivation

Refactoring is all about manipulating the elements of our programs. Data is more awkward to manipulate than functions. Since using a function usually means calling it, I can easily rename or move a function while keeping the old function intact as a forwarding function (so my old code calls the old function, which calls the new function). I'll usually not keep this forwarding function around for long, but it does simplify the refactoring.

Data is more awkward because I can't do that. If I move data around, I have to change all the references to the data in a single cycle to keep the code working. For data with a very small scope of access, such as a temporary variable in a small function, this isn't a problem. But as the scope grows, so does the difficulty, which is why global data is such a pain.

So if I want to move widely accessed data, often the best approach is to first encapsulate it by routing all its access through functions. That way, I turn the difficult task of reorganizing data into the simpler task of reorganizing functions.

Encapsulating data is valuable for other things too. It provides a clear point to monitor changes and use of the data; I can easily add validation or consequential logic on the updates. It is my habit to make all mutable data encapsulated like this and only accessed through functions if its scope is greater than a single function. The greater the scope of the data, the more important it is to encapsulate.

My approach with legacy code is that whenever I need to change or add a new reference to such a variable, I should take the opportunity to encapsulate it. That way I prevent the increase of coupling to commonly used data.

This principle is why the object-oriented approach puts so much emphasis on keeping an object's data private. Whenever I see a public field, I consider using Encapsulate Variable (in that case often called *Encapsulate Field*) to reduce its visibility. Some go further and argue that even internal references to fields within a class should go through accessor functions—an approach known as self-encapsulation. On the whole, I find self-encapsulation excessive—if a class is so big that I need to self-encapsulate its fields, it needs to be broken up anyway. But self-encapsulating a field is a useful step before splitting a class.

Keeping data encapsulated is much less important for immutable data. When the data doesn't change, I don't need a place to put in validation or other logic hooks before updates. I can also freely copy the data rather than move it—so I don't have to change references from old locations, nor do I worry about sections of code getting stale data. Immutability is a powerful preservative.

Mechanics

- Create encapsulating functions to access and update the variable.
- Run static checks.
- For each reference to the variable, replace with a call to the appropriate encapsulating function. Test after each replacement.
- Restrict the visibility of the variable.

Sometimes it's not possible to prevent access to the variable. If so, it may be useful to detect any remaining references by renaming the variable and testing.

- Test.
- If the value of the variable is a record, consider *Encapsulate Record* (162).

Example

Consider some useful data held in a global variable.

```
let defaultOwner = {firstName: "Martin", lastName: "Fowler"};
```

Like any data, it's referenced with code like this:

```
spaceship.owner = defaultOwner;
```

and updated like this:

```
defaultOwner = {firstName: "Rebecca", lastName: "Parsons"};
```

To do a basic encapsulation on this, I start by defining functions to read and write the data.

```
function getDefaultOwner() {return defaultOwner;}
function setDefaultOwner(arg) {defaultOwner = arg;}
```

I then start working on references to `defaultOwner`. When I see a reference, I replace it with a call to the getting function.

```
spaceship.owner = getDefaultOwner();
```

When I see an assignment, I replace it with the setting function.

```
setDefaultOwner({firstName: "Rebecca", lastName: "Parsons"});
```

I test after each replacement.

Once I'm done with all the references, I restrict the visibility of the variable. This both checks that there aren't any references that I've missed, and ensures that future changes to the code won't access the variable directly. I can do that in JavaScript by moving both the variable and the accessor methods to their own file and only exporting the accessor methods.

defaultOwner.js...

```
let defaultOwner = {firstName: "Martin", lastName: "Fowler"};
export function getDefaultOwner() {return defaultOwner;}
export function setDefaultOwner(arg) {defaultOwner = arg;}
```

If I'm in a situation where I cannot restrict the access to a variable, it may be useful to rename the variable and retest. That won't prevent future direct access, but naming the variable something meaningful and awkward such as `_privateOnly_defaultOwner` may help.

I don't like the use of get prefixes on getters, so I'll rename to remove it.

defaultOwner.js...

```
let defaultOwnerData = {firstName: "Martin", lastName: "Fowler"};
export function getdefaultOwner() {return defaultOwnerData;}
export function setDefaultOwner(arg) {defaultOwnerData = arg;}
```

A common convention in JavaScript is to name a getting function and setting function the same and differentiate them due the presence of an argument. I call this practice Overloaded Getter Setter [mf-ogs] and strongly dislike it. So, even though I don't like the get prefix, I will keep the set prefix.

Encapsulating the Value

The basic refactoring I've outlined here encapsulates a reference to some data structure, allowing me to control its access and reassignment. But it doesn't control changes to that structure.

```
const owner1 = defaultOwner();
assert.equal("Fowler", owner1.lastName, "when set");
const owner2 = defaultOwner();
owner2.lastName = "Parsons";
assert.equal("Parsons", owner1.lastName, "after change owner2"); // is this ok?
```

The basic refactoring encapsulates the reference to the data item. In many cases, this is all I want to do for the moment. But I often want to take the encapsulation deeper to control not just changes to the variable but also to its contents.

For this, I have a couple of options. The simplest one is to prevent any changes to the value. My favorite way to handle this is by modifying the getting function to return a copy of the data.

defaultOwner.js...

```
let defaultOwnerData = {firstName: "Martin", lastName: "Fowler"};
export function defaultOwner() {return Object.assign({}, defaultOwnerData);}
export function setDefaultOwner(arg) {defaultOwnerData = arg;}
```

I use this approach particularly often with lists. If I return a copy of the data, any clients using it can change it, but that change isn't reflected in the shared data. I have to be careful with using copies, however: Some code may expect to change shared data. If that's the case, I'm relying on my tests to detect a problem. An alternative is to prevent changes—and a good way of doing that is *Encapsulate Record* (162).

```
let defaultOwnerData = {firstName: "Martin", lastName: "Fowler"};
export function defaultOwner() {return new Person(defaultOwnerData);}
export function setDefaultOwner(arg) {defaultOwnerData = arg;}

class Person {
  constructor(data) {
    this._lastName = data.lastName;
    this._firstName = data.firstName
  }
  get lastName() {return this._lastName;}
  get firstName() {return this._firstName;}
  // and so on for other properties
```

Now, any attempt to reassign the properties of the default owner will cause an error. Different languages have different techniques to detect or prevent changes like this, so depending on the language I'd consider other options.

Detecting and preventing changes like this is often worthwhile as a temporary measure. I can either remove the changes, or provide suitable mutating functions. Then, once they are all dealt with, I can modify the getting method to return a copy.

So far I've talked about copying on getting data, but it may be worthwhile to make a copy in the setter too. That will depend on where the data comes from and whether I need to maintain a link to reflect any changes in that original data.

If I don't need such a link, a copy prevents accidents due to changes on that source data. Taking a copy may be superfluous most of the time, but copies in these cases usually have a negligible effect on performance; on the other hand, if I don't do them, there is a risk of a long and difficult bout of debugging in the future.

Remember that the copying above, and the class wrapper, both only work one level deep in the record structure. Going deeper requires more levels of copies or object wrapping.

As you can see, encapsulating data is valuable, but often not straightforward. Exactly what to encapsulate—and how to do it—depends on the way the data is being used and the changes I have in mind. But the more widely it's used, the more it's worth my attention to encapsulate properly.

Rename Variable



```
let a = height * width;
```



```
let area = height * width;
```

Motivation

Naming things well is the heart of clear programming. Variables can do a lot to explain what I'm up to—if I name them well. But I frequently get my names wrong—sometimes because I'm not thinking carefully enough, sometimes because my understanding of the problem improves as I learn more, and sometimes because the program's purpose changes as my users' needs change.

Even more than most program elements, the importance of a name depends on how widely it's used. A variable used in a one-line lambda expression is usually easy to follow—I often use a single letter in that case since the variable's purpose is clear from its context. Parameters for short functions can often be terse for the same reason, although in a dynamically typed language like JavaScript, I do like to put the type into the name (hence parameter names like `aCustomer`).

Persistent fields that last beyond a single function invocation require more careful naming. This is where I'm likely to put most of my attention.

Mechanics

- If the variable is used widely, consider *Encapsulate Variable* (132).
- Find all references to the variable, and change every one.

If there are references from another code base, the variable is a published variable, and you cannot do this refactoring.

If the variable does not change, you can copy it to one with the new name, then change gradually, testing after each change.

- Test.

Example

The simplest case for renaming a variable is when it's local to a single function: a temp or argument. It's too trivial for even an example: I just find each reference and change it. After I'm done, I test to ensure I didn't mess up.

Problems occur when the variable has a wider scope than just a single function. There may be a lot of references all over the code base:

```
let tpHd = "untitled";
```

Some references access the variable:

```
result += `<h1>${tpHd}</h1>`;
```

Others update it:

```
tpHd = obj['articleTitle'];
```

My usual response to this is apply *Encapsulate Variable* (132).

```
result += `<h1>${title()}</h1>`;
```

```
setTitle(obj['articleTitle']);
```

```
function title()    {return tpHd;}
```

```
function setTitle(arg) {tpHd = arg;}
```

At this point, I can rename the variable.

```
let _title = "untitled";
```

```
function title()    {return _title;}
```

```
function setTitle(arg) {_title = arg;}
```

I could continue by inlining the wrapping functions so all callers are using the variable directly. But I'd rarely want to do this. If the variable is used widely enough that I feel the need to encapsulate it in order to change its name, it's worth keeping it encapsulated behind functions for the future.

In cases where I was going to inline, I'd call the getting function `getTitle` and not use an underscore for the variable name when I rename it.

Renaming a Constant

If I'm renaming a constant (or something that acts like a constant to clients) I can avoid encapsulation, and still do the rename gradually, by copying. If the original declaration looks like this:

```
const cpyNm = "Acme Gooseberries";
```

I can begin the renaming by making a copy:


```
const companyName = "Acme Gooseberries";  
const cpyNm = companyName;
```

With the copy, I can gradually change references from the old name to the new name. When I'm done, I remove the copy. I prefer to declare the new name and copy to the old name if it makes it a tad easier to remove the old name and put it back again should a test fail.

This works for constants as well as for variables that are read-only to clients (such as an exported variable in JavaScript).

Introduce Parameter Object



```
function amountInvoiced(startDate, endDate) {...}  
function amountReceived(startDate, endDate) {...}  
function amountOverdue(startDate, endDate) {...}
```



```
function amountInvoiced(aDateRange) {...}  
function amountReceived(aDateRange) {...}  
function amountOverdue(aDateRange) {...}
```

Motivation

I often see groups of data items that regularly travel together, appearing in function after function. Such a group is a data clump, and I like to replace it with a single data structure.

Grouping data into a structure is valuable because it makes explicit the relationship between the data items. It reduces the size of parameter lists for any function that uses the new structure. It helps consistency since all functions that use the structure will use the same names to get at its elements.

But the real power of this refactoring is how it enables deeper changes to the code. When I identify these new structures, I can reorient the behavior of the program to use these structures. I will create functions that capture the common behavior over this data—either as a set of common functions or as a class that combines the data structure with these functions. This process can change the conceptual picture of the code, raising these structures as new abstractions that can greatly simplify my understanding of the domain. When this works, it can have surprisingly powerful effects—but none of this is possible unless I use Introduce Parameter Object to begin the process.

Mechanics

- If there isn't a suitable structure already, create one.

I prefer to use a class, as that makes it easier to group behavior later on. I usually like to ensure these structures are value objects [mf-vo].

- Test.
- Use *Change Function Declaration (124)* to add a parameter for the new structure.
- Test.
- Adjust each caller to pass in the correct instance of the new structure. Test after each one.
- For each element of the new structure, replace the use of the original parameter with the element of the structure. Remove the parameter. Test.

Example

I'll begin with some code that looks at a set of temperature readings and determines whether any of them fall outside of an operating range. Here's what the data looks like for the readings:

```
const station = { name: "ZB1",
  readings: [
    {temp: 47, time: "2016-11-10 09:10"},
    {temp: 53, time: "2016-11-10 09:20"},
    {temp: 58, time: "2016-11-10 09:30"},
    {temp: 53, time: "2016-11-10 09:40"},
    {temp: 51, time: "2016-11-10 09:50"},
  ]
};
```

I have a function to find the readings that are outside a temperature range.

```
function readingsOutsideRange(station, min, max) {
  return station.readings
    .filter(r => r.temp < min || r.temp > max);
}
```

It might be called from some code like this:

caller

```
alerts = readingsOutsideRange(station,
  operatingPlan.temperatureFloor,
  operatingPlan.temperatureCeiling);
```

Notice how the calling code pulls the two data items as a pair from another object and passes the pair into `readingsOutsideRange`. The operating plan uses different names to indicate the start and end of the range compared to `readingsOutsideRange`. A range like this is a common case where two separate data items are better combined into a single object. I'll begin by declaring a class for the combined data.

```
class NumberRange {
  constructor(min, max) {
    this._data = {min: min, max: max};
  }
  get min() {return this._data.min;}
  get max() {return this._data.max;}
}
```

I declare a class, rather than just using a basic JavaScript object, because I usually find this refactoring to be a first step to moving behavior into the newly created object. Since a class makes sense for this, I go right ahead and use one directly. I also don't provide any update methods for the new class, as I'll probably make this a Value Object [mf-vo]. Most times I do this refactoring, I create value objects.

I then use *Change Function Declaration (124)* to add the new object as a parameter to `readingsOutsideRange`.

```
function readingsOutsideRange(station, min, max, range) {
  return station.readings
    .filter(r => r.temp < min || r.temp > max);
}
```

In JavaScript, I can leave the caller as is, but in other languages I'd have to add a null for the new parameter which would look something like this:

caller

```
alerts = readingsOutsideRange(station,
                              operatingPlan.temperatureFloor,
                              operatingPlan.temperatureCeiling,
                              null);
```

At this point I haven't changed any behavior, and tests should still pass. I then go to each caller and adjust it to pass in the correct date range.

caller

```
const range = new NumberRange(operatingPlan.temperatureFloor, operatingPlan.temperatureCeiling);
alerts = readingsOutsideRange(station,
                              operatingPlan.temperatureFloor,
                              operatingPlan.temperatureCeiling,
                              range);
```

I still haven't altered any behavior yet, as the parameter isn't used. All tests should still work.

Now I can start replacing the usage of the parameters. I'll start with the maximum.

```
function readingsOutsideRange(station, min, max, range) {
  return station.readings
    .filter(r => r.temp < min || r.temp > range.max);
}
```

caller

```
const range = new NumberRange(operatingPlan.temperatureFloor, operatingPlan.temperatureCeiling);
alerts = readingsOutsideRange(station,
  operatingPlan.temperatureFloor,
  operatingPlan.temperatureCeiling,
  range);
```

I can test at this point, then remove the other parameter.

```
function readingsOutsideRange(station, min, range) {
  return station.readings
    .filter(r => r.temp < range.min || r.temp > range.max);
}
```

caller

```
const range = new NumberRange(operatingPlan.temperatureFloor, operatingPlan.temperatureCeiling);
alerts = readingsOutsideRange(station,
  operatingPlan.temperatureFloor,
  range);
```

That completes this refactoring. However, replacing a clump of parameters with a real object is just the setup for the really good stuff. The great benefits of making a class like this is that I can then move behavior into the new class. In this case, I'd add a method for range that tests if a value falls within the range.

```
function readingsOutsideRange(station, range) {
  return station.readings
    .filter(r => !range.contains(r.temp));
}
```

class NumberRange...

```
contains(arg) {return (arg >= this.min && arg <= this.max);}
```

This is a first step to creating a range [mf-range] that can take on a lot of useful behavior. Once I've identified the need for a range in my code, I can be constantly on the lookout for other cases where I see a max/min pair of numbers and replace them with a range. (One immediate possibility is the operating plan, replacing temperatureFloor and temperatureCeiling with a temperatureRange.) As I look at how these pairs are used, I can move more useful behavior into the range class, simplifying its usage across the code base. One of the first things I may add is a value-based equality method to make it a true value object.

Combine Functions into Class



```
function base(aReading) {...}
function taxableCharge(aReading) {...}
function calculateBaseCharge(aReading) {...}
```



```
class Reading {
  base() {...}
  taxableCharge() {...}
  calculateBaseCharge() {...}
}
```

Motivation

Classes are a fundamental construct in most modern programming languages. They bind together data and functions into a shared environment, exposing some of that data and function to other program elements for collaboration. They are the primary construct in object-oriented languages, but are also useful with other approaches too.

When I see a group of functions that operate closely together on a common body of data (usually passed as arguments to the function call), I see an opportunity to form a class. Using a class makes the common environment that these functions share more explicit, allows me to simplify function calls inside the object by removing many of the arguments, and provides a reference to pass such an object to other parts of the system.

In addition to organizing already formed functions, this refactoring also provides a good opportunity to identify other bits of computation and refactor them into methods on the new class.

Another way of organizing functions together is *Combine Functions into Transform (149)*. Which one to use depends more on the broader context of the program. One significant advantage of using a class is that it allows clients to mutate the core data of the object, and the derivations remain consistent.

As well as a class, functions like this can also be combined into a nested function. Usually I prefer a class to a nested function, as it can be difficult to test functions nested within another. Classes are also necessary when there is more than one function in the group that I want to expose to collaborators.

Languages that don't have classes as a first-class element, but do have first-class functions, often use the Function As Object [mf-fao] to provide this capability.

Mechanics

- Apply *Encapsulate Record* (162) to the common data record that the functions share.

If the data that is common between the functions isn't already grouped into a record structure, use *Introduce Parameter Object* (140) to create a record to group it together.

- Take each function that uses the common record and use *Move Function* (198) to move it into the new class.

Any arguments to the function call that are members can be removed from the argument list.

- Each bit of logic that manipulates the data can be extracted with *Extract Function* (106) and then moved into the new class.

Example

I grew up in England, a country renowned for its love of Tea. (Personally, I don't like most tea they serve in England, but have since acquired a taste for Chinese and Japanese teas.) So my author's fantasy conjures up a state utility for providing tea to the population. Every month they read the tea meters, to get a record like this:

```
reading = {customer: "ivan", quantity: 10, month: 5, year: 2017};
```

I look through the code that processes these records, and I see lots of places where similar calculations are done on the data. So I find a spot that calculates the base charge:

client 1...

```
const aReading = acquireReading();
const baseCharge = baseRate(aReading.month, aReading.year) * aReading.quantity;
```

Being England, everything essential must be taxed, so it is with tea. But the rules allow at least an essential level of tea to be free of taxation.

client 2...

```
const aReading = acquireReading();
const base = (baseRate(aReading.month, aReading.year) * aReading.quantity);
const taxableCharge = Math.max(0, base - taxThreshold(aReading.year));
```

I'm sure that, like me, you noticed that the formula for the base charge is duplicated between these two fragments. If you're like me, you're already reaching for *Extract Function* (106). Interestingly, it seems our work has been done for us elsewhere.

client 3...

```
const aReading = acquireReading();
const basicChargeAmount = calculateBaseCharge(aReading);

function calculateBaseCharge(aReading) {
  return baseRate(aReading.month, aReading.year) * aReading.quantity;
}
```

Given this, I have a natural impulse to change the two earlier bits of client code to use this function. But the trouble with top-level functions like this is that they are often easy to miss. I'd rather change the code to give the function a closer connection to the data it processes. A good way to do this is to turn the data into a class.

To turn the record into a class, I use *Encapsulate Record* (162).

```
class Reading {
  constructor(data) {
    this._customer = data.customer;
    this._quantity = data.quantity;
    this._month = data.month;
    this._year = data.year;
  }
  get customer() {return this._customer;}
  get quantity() {return this._quantity;}
  get month() {return this._month;}
  get year() {return this._year;}
}
```

To move the behavior, I'll start with the function I already have: `calculateBaseCharge`. To use the new class, I need to apply it to the data as soon as I've acquired it.

client 3...

```
const rawReading = acquireReading();
const aReading = new Reading(rawReading);
const basicChargeAmount = calculateBaseCharge(aReading);
```

I then use *Move Function* (198) to move `calculateBaseCharge` into the new class.

class Reading...

```
get calculateBaseCharge() {
  return baseRate(this.month, this.year) * this.quantity;
}
```

client 3...

```
const rawReading = acquireReading();
const aReading = new Reading(rawReading);
const basicChargeAmount = aReading.calculateBaseCharge;
```

While I'm at it, I use *Rename Function (124)* to make it something more to my liking.

```
get baseCharge() {
  return baseRate(this.month, this.year) * this.quantity;
}
```

client 3...

```
const rawReading = acquireReading();
const aReading = new Reading(rawReading);
const basicChargeAmount = aReading.baseCharge;
```

With this naming, the client of the reading class can't tell whether the base charge is a field or a derived value. This is a Good Thing—the Uniform Access Principle [mf-ua].

I now alter the first client to call the method rather than repeat the calculation.

client 1...

```
const rawReading = acquireReading();
const aReading = new Reading(rawReading);
const baseCharge = aReading.baseCharge;
```

There's a strong chance I'll use *Inline Variable (123)* on the baseCharge variable before the day is out. But more relevant to this refactoring is the client that calculates the taxable amount. My first step here is to use the new base charge property.

client 2...

```
const rawReading = acquireReading();
const aReading = new Reading(rawReading);
const taxableCharge = Math.max(0, aReading.baseCharge - taxThreshold(aReading.year));
```

I use *Extract Function (106)* on the calculation for the taxable charge.

```
function taxableChargeFn(aReading) {
  return Math.max(0, aReading.baseCharge - taxThreshold(aReading.year));
}
```

client 3...

```
const rawReading = acquireReading();  
const aReading = new Reading(rawReading);  
const taxableCharge = taxableChargeFn(aReading);
```

Then I apply *Move Function (198)*.

class Reading...

```
get taxableCharge() {  
  return Math.max(0, this.baseCharge - taxThreshold(this.year));  
}
```

client 3...

```
const rawReading = acquireReading();  
const aReading = new Reading(rawReading);  
const taxableCharge = aReading.taxableCharge;
```

Since all the derived data is calculated on demand, I have no problem should I need to update the stored data. In general, I prefer immutable data, but many circumstances force us to work with mutable data (such as JavaScript, a language ecosystem that wasn't designed with immutability in mind). When there is a reasonable chance the data will be updated somewhere in the program, then a class is very helpful.

Combine Functions into Transform



```
function base(aReading) {...}
function taxableCharge(aReading) {...}
```



```
function enrichReading(argReading) {
  const aReading = _.cloneDeep(argReading);
  aReading.baseCharge = base(aReading);
  aReading.taxableCharge = taxableCharge(aReading);
  return aReading;
}
```

Motivation

Software often involves feeding data into programs that calculate various derived information from it. These derived values may be needed in several places, and those calculations are often repeated wherever the derived data is used. I prefer to bring all of these derivations together, so I have a consistent place to find and update them and avoid any duplicate logic.

One way to do this is to use a data transformation function that takes the source data as input and calculates all the derivations, putting each derived value as a field in the output data. Then, to examine the derivations, all I need do is look at the transform function.

An alternative to Combine Functions into Transform is *Combine Functions into Class (144)* that moves the logic into methods on a class formed from the source data. Either of these refactorings are helpful, and my choice will often depend on the style of programming already in the software. But there is one important difference: Using a class is much better if the source data gets updated within the code. Using a transform stores derived data in the new record, so if the source data changes, I will run into inconsistencies.

One of the reasons I like to do combine functions is to avoid duplication of the derivation logic. I can do that just by using *Extract Function (106)* on the logic, but it's often difficult to find the functions unless they are kept close to the data structures they operate on. Using a transform (or a class) makes it easy to find and use them.

Mechanics

- Create a transformation function that takes the record to be transformed and returns the same values.

This will usually involve a deep copy of the record. It is often worthwhile to write a test to ensure the transform does not alter the original record.

- Pick some logic and move its body into the transform to create a new field in the record. Change the client code to access the new field.

If the logic is complex, use *Extract Function (106)* first.

- Test.
- Repeat for the other relevant functions.

Example

Where I grew up, tea is an important part of life—so much that I can imagine a special utility that provides tea to the populace that's regulated like a utility. Every month, the utility gets a reading of how much tea a customer has acquired.

```
reading = {customer: "ivan", quantity: 10, month: 5, year: 2017};
```

Code in various places calculates various consequences of this tea usage. One such calculation is the base monetary amount that's used to calculate the charge for the customer.

client 1...

```
const aReading = acquireReading();
const baseCharge = baseRate(aReading.month, aReading.year) * aReading.quantity;
```

Another is the amount that should be taxed—which is less than the base amount since the government wisely considers that every citizen should get some tea tax free.

client 2...

```
const aReading = acquireReading();
const base = (baseRate(aReading.month, aReading.year) * aReading.quantity);
const taxableCharge = Math.max(0, base - taxThreshold(aReading.year));
```

Looking through this code, I see these calculations repeated in several places. Such duplication is asking for trouble when they need to change (and I'd bet it's "when" not "if"). I can deal with this repetition by using *Extract Function (106)* on these calculations, but such functions often end up scattered around the program making it hard for future developers to realize they are there. Indeed, looking around I discover such a function, used in another area of the code.

client 3...

```
const aReading = acquireReading();
const basicChargeAmount = calculateBaseCharge(aReading);

function calculateBaseCharge(aReading) {
  return baseRate(aReading.month, aReading.year) * aReading.quantity;
}
```

One way of dealing with this is to move all of these derivations into a transformation step that takes the raw reading and emits a reading enriched with all the common derived results.

I begin by creating a transformation function that merely copies the input object.

```
function enrichReading(original) {
  const result = _.cloneDeep(original);
  return result;
}
```

I'm using the cloneDeep from lodash to create a deep copy.

When I'm applying a transformation that produces essentially the same thing but with additional information, I like to name it using "enrich". If it were producing something I felt was different, I would name it using "transform".

I then pick one of the calculations I want to change. First, I enrich the reading it uses with the current one that does nothing yet.

client 3...

```
const rawReading = acquireReading();
const aReading = enrichReading(rawReading);
const basicChargeAmount = calculateBaseCharge(aReading);
```

I use *Move Function (198)* on calculateBaseCharge to move it into the enrichment calculation.

```
function enrichReading(original) {
  const result = _.cloneDeep(original);
  result.baseCharge = calculateBaseCharge(result);
  return result;
}
```

Within the transformation function, I'm happy to mutate a result object, instead of copying each time. I like immutability, but most common languages make it difficult to work with. I'm prepared to go through the extra effort to support

it at boundaries, but will mutate within smaller scopes. I also pick my names (using `aReading` as the accumulating variable) to make it easier to move the code into the transformer function.

I change the client that uses that function to use the enriched field instead.

client 3...

```
const rawReading = acquireReading();
const aReading = enrichReading(rawReading);
const basicChargeAmount = aReading.baseCharge;
```

Once I've moved all calls to `calculateBaseCharge`, I can nest it inside `enrichReading`. That would make it clear that clients that need the calculated base charge should use the enriched record.

One trap to beware of here. When I write `enrichReading` like this, to return the enriched reading, I'm implying that the original reading record isn't changed. So it's wise for me to add a test.

```
it('check reading unchanged', function() {
  const baseReading = {customer: "ivan", quantity: 15, month: 5, year: 2017};
  const oracle = _.cloneDeep(baseReading);
  enrichReading(baseReading);
  assert.deepEqual(baseReading, oracle);
});
```

I can then change client 1 to also use the same field.

client 1...

```
const rawReading = acquireReading();
const aReading = enrichReading(rawReading);
const baseCharge = aReading.baseCharge;
```

There is a good chance I can then use *Inline Variable (123)* on `baseCharge` too.

Now I turn to the taxable amount calculation. My first step is to add in the transformation function.

```
const rawReading = acquireReading();
const aReading = enrichReading(rawReading);
const base = (baseRate(aReading.month, aReading.year) * aReading.quantity);
const taxableCharge = Math.max(0, base - taxThreshold(aReading.year));
```

I can immediately replace the calculation of the base charge with the new field. If the calculation was complex, I could *Extract Function (106)* first, but here it's simple enough to do in one step.

```
const rawReading = acquireReading();
const aReading = enrichReading(rawReading);
const base = aReading.baseCharge;
const taxableCharge = Math.max(0, base - taxThreshold(aReading.year));
```

Once I've tested that that works, I apply *Inline Variable (123)*:

```
const rawReading = acquireReading();
const aReading = enrichReading(rawReading);
const taxableCharge = Math.max(0, aReading.baseCharge - taxThreshold(aReading.year));
```

and move that computation into the transformer:

```
function enrichReading(original) {
  const result = _.cloneDeep(original);
  result.baseCharge = calculateBaseCharge(result);
  result.taxableCharge = Math.max(0, result.baseCharge - taxThreshold(result.year));
  return result;
}
```

I modify the original code to use the new field.

```
const rawReading = acquireReading();
const aReading = enrichReading(rawReading);
const taxableCharge = aReading.taxableCharge;
```

Once I've tested that, it's likely I would be able to use *Inline Variable (123)* on `taxableCharge`.

One big problem with an enriched reading like this is: What happens should a client change a data value? Changing, say, the `quantity` field would result in data that's inconsistent. To avoid this in JavaScript, my best option is to use *Combine Functions into Class (144)* instead. If I'm in a language with immutable data structures, I don't have this problem, so it's more common to see transforms in those languages. But even in languages without immutability, I can use transforms if the data appears in a read-only context, such as deriving data to display on a web page.

Split Phase



```
const orderData = orderString.split(/\s+/);
const productPrice = priceList[orderData[0].split("-")[1]];
const orderPrice = parseInt(orderData[1]) * productPrice;
```



```
const orderRecord = parseOrder(order);
const orderPrice = price(orderRecord, priceList);

function parseOrder(aString) {
  const values = aString.split(/\s+/);
  return ({
    productID: values[0].split("-")[1],
    quantity: parseInt(values[1]),
  });
}

function price(order, priceList) {
  return order.quantity * priceList[order.productID];
}
```

Motivation

When I run into code that's dealing with two different things, I look for a way to split it into separate modules. I endeavor to make this split because, if I need to make a change, I can deal with each topic separately and not have to hold both in my head together. If I'm lucky, I may only have to change one module without having to remember the details of the other one at all.

One of the neatest ways to do a split like this is to divide the behavior into two sequential phases. A good example of this is when you have some processing whose inputs don't reflect the model you need to carry out the logic. Before you begin, you can massage the input into a convenient form for your main processing.

Or, you can take the logic you need to do and break it down into sequential steps, where each step is significantly different in what it does.

The most obvious example of this is a compiler. It's a basic task is to take some text (code in a programming language) and turn it into some executable form (e.g., object code for a specific hardware). Over time, we've found this can be usefully split into a chain of phases: tokenizing the text, parsing the tokens into a syntax tree, then various steps of transforming the syntax tree (e.g., for optimization), and finally generating the object code. Each step has a limited scope and I can think of one step without understanding the details of others.

Splitting phases like this is common in large software; the various phases in a compiler can each contain many functions and classes. But I can carry out the basic split-phase refactoring on any fragment of code—whenever I see an opportunity to usefully separate the code into different phases. The best clue is when different stages of the fragment use different sets of data and functions. By turning them into separate modules I can make this difference explicit, revealing the difference in the code.

Mechanics

- Extract the second phase code into its own function.
- Test.
- Introduce an intermediate data structure as an additional argument to the extracted function.
- Test.
- Examine each parameter of the extracted second phase. If it is used by first phase, move it to the intermediate data structure. Test after each move.

Sometimes, a parameter should not be used by the second phase. In this case, extract the results of each usage of the parameter into a field of the intermediate data structure and use *Move Statements to Callers* (217) on the line that populates it.

- Apply *Extract Function* (106) on the first-phase code, returning the intermediate data structure.

It's also reasonable to extract the first phase into a transformer object.

Example

I'll start with code to price an order for some vague and unimportant kind of goods:

```
function priceOrder(product, quantity, shippingMethod) {
  const basePrice = product.basePrice * quantity;
  const discount = Math.max(quantity - product.discountThreshold, 0)
    * product.basePrice * product.discountRate;
  const shippingPerCase = (basePrice > shippingMethod.discountThreshold)
    ? shippingMethod.discountedFee : shippingMethod.feePerCase;
  const shippingCost = quantity * shippingPerCase;
  const price = basePrice - discount + shippingCost;
  return price;
}
```

Although this is the usual kind of trivial example, there is a sense of two phases going on here. The first couple of lines of code use the product information to calculate the product-oriented price of the order, while the later code uses shipping information to determine the shipping cost. If I have changes coming up that complicate the pricing and shipping calculations, but they work relatively independently, then splitting this code into two phases is valuable.

I begin by applying *Extract Function (106)* to the shipping calculation.

```
function priceOrder(product, quantity, shippingMethod) {
  const basePrice = product.basePrice * quantity;
  const discount = Math.max(quantity - product.discountThreshold, 0)
    * product.basePrice * product.discountRate;
  const price = applyShipping(basePrice, shippingMethod, quantity, discount);
  return price;
}
function applyShipping(basePrice, shippingMethod, quantity, discount) {
  const shippingPerCase = (basePrice > shippingMethod.discountThreshold)
    ? shippingMethod.discountedFee : shippingMethod.feePerCase;
  const shippingCost = quantity * shippingPerCase;
  const price = basePrice - discount + shippingCost;
  return price;
}
```

I pass in all the data that this second phase needs as individual parameters. In a more realistic case, there can be a lot of these, but I don't worry about it as I'll whittle them down later.

Next, I introduce the intermediate data structure that will communicate between the two phases.

```
function priceOrder(product, quantity, shippingMethod) {
  const basePrice = product.basePrice * quantity;
  const discount = Math.max(quantity - product.discountThreshold, 0)
    * product.basePrice * product.discountRate;
  const priceData = {};
  const price = applyShipping(priceData, basePrice, shippingMethod, quantity, discount);
  return price;
}
```

```
function applyShipping(priceData, basePrice, shippingMethod, quantity, discount) {
  const shippingPerCase = (basePrice > shippingMethod.discountThreshold)
    ? shippingMethod.discountedFee : shippingMethod.feePerCase;
  const shippingCost = quantity * shippingPerCase;
  const price = basePrice - discount + shippingCost;
  return price;
}
```

Now, I look at the various parameters to `applyShipping`. The first one is `basePrice` which is created by the first-phase code. So I move this into the intermediate data structure, removing it from the parameter list.

```
function priceOrder(product, quantity, shippingMethod) {
  const basePrice = product.basePrice * quantity;
  const discount = Math.max(quantity - product.discountThreshold, 0)
    * product.basePrice * product.discountRate;
  const priceData = {basePrice: basePrice};
  const price = applyShipping(priceData, basePrice, shippingMethod, quantity, discount);
  return price;
}

function applyShipping(priceData, basePrice, shippingMethod, quantity, discount) {
  const shippingPerCase = (priceData.basePrice > shippingMethod.discountThreshold)
    ? shippingMethod.discountedFee : shippingMethod.feePerCase;
  const shippingCost = quantity * shippingPerCase;
  const price = priceData.basePrice - discount + shippingCost;
  return price;
}
```

The next parameter in the list is `shippingMethod`. This one I leave as is, since it isn't used by the first-phase code.

After this, I have `quantity`. This is used by the first phase but not created by it, so I could actually leave this in the parameter list. My usual preference, however, is to move as much as I can to the intermediate data structure.

```
function priceOrder(product, quantity, shippingMethod) {
  const basePrice = product.basePrice * quantity;
  const discount = Math.max(quantity - product.discountThreshold, 0)
    * product.basePrice * product.discountRate;
  const priceData = {basePrice: basePrice, quantity: quantity};
  const price = applyShipping(priceData, shippingMethod, quantity, discount);
  return price;
}

function applyShipping(priceData, shippingMethod, quantity, discount) {
  const shippingPerCase = (priceData.basePrice > shippingMethod.discountThreshold)
    ? shippingMethod.discountedFee : shippingMethod.feePerCase;
  const shippingCost = priceData.quantity * shippingPerCase;
  const price = priceData.basePrice - discount + shippingCost;
  return price;
}
```

I do the same with discount.

```
function priceOrder(product, quantity, shippingMethod) {
  const basePrice = product.basePrice * quantity;
  const discount = Math.max(quantity - product.discountThreshold, 0)
    * product.basePrice * product.discountRate;
  const priceData = {basePrice: basePrice, quantity: quantity, discount:discount};
  const price = applyShipping(priceData, shippingMethod, discount);
  return price;
}
function applyShipping(priceData, shippingMethod, discount) {
  const shippingPerCase = (priceData.basePrice > shippingMethod.discountThreshold)
    ? shippingMethod.discountedFee : shippingMethod.feePerCase;
  const shippingCost = priceData.quantity * shippingPerCase;
  const price = priceData.basePrice - priceData.discount + shippingCost;
  return price;
}
```

Once I've gone through all the function parameters, I have the intermediate data structure fully formed. So I can extract the first-phase code into its own function, returning this data.

```
function priceOrder(product, quantity, shippingMethod) {
  const priceData = calculatePricingData(product, quantity);
  const price = applyShipping(priceData, shippingMethod);
  return price;
}
function calculatePricingData(product, quantity) {
  const basePrice = product.basePrice * quantity;
  const discount = Math.max(quantity - product.discountThreshold, 0)
    * product.basePrice * product.discountRate;
  return {basePrice: basePrice, quantity: quantity, discount:discount};
}
function applyShipping(priceData, shippingMethod) {
  const shippingPerCase = (priceData.basePrice > shippingMethod.discountThreshold)
    ? shippingMethod.discountedFee : shippingMethod.feePerCase;
  const shippingCost = priceData.quantity * shippingPerCase;
  const price = priceData.basePrice - priceData.discount + shippingCost;
  return price;
}
```

I can't resist tidying out those final constants.

```
function priceOrder(product, quantity, shippingMethod) {
  const priceData = calculatePricingData(product, quantity);
  return applyShipping(priceData, shippingMethod);
}
```

```
function calculatePricingData(product, quantity) {
  const basePrice = product.basePrice * quantity;
  const discount = Math.max(quantity - product.discountThreshold, 0)
    * product.basePrice * product.discountRate;
  return {basePrice: basePrice, quantity: quantity, discount:discount};
}

function applyShipping(priceData, shippingMethod) {
  const shippingPerCase = (priceData.basePrice > shippingMethod.discountThreshold)
    ? shippingMethod.discountedFee : shippingMethod.feePerCase;
  const shippingCost = priceData.quantity * shippingPerCase;
  return priceData.basePrice - priceData.discount + shippingCost;
}
```

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Chapter 7

Encapsulation

Perhaps the most important criteria to be used in decomposing modules is to identify secrets that modules should hide from the rest of the system [Parnas]. Data structures are the most common secrets, and I can hide data structures by encapsulating them with *Encapsulate Record* (162) and *Encapsulate Collection* (170). Even primitive data values can be encapsulated with *Replace Primitive with Object* (174)—the magnitude of second-order benefits from doing this often surprises people. Temporary variables often get in the way of refactoring—I have to ensure they are calculated in the right order and their values are available to other parts of the code that need them. Using *Replace Temp with Query* (178) is a great help here, particularly when splitting up an overly long function.

Classes were designed for information hiding. In the previous chapter, I described a way to form them with *Combine Functions into Class* (144). The common extract/inline operations also apply to classes with *Extract Class* (182) and *Inline Class* (186).

As well as hiding the internals of classes, it's often useful to hide connections between classes, which I can do with *Hide Delegate* (189). But too much hiding leads to bloated interfaces, so I also need its reverse: *Remove Middle Man* (192).

Classes and modules are the largest forms of encapsulation, but functions also encapsulate their implementation. Sometimes, I may need to make a wholesale change to an algorithm, which I can do by wrapping it in a function with *Extract Function* (106) and applying *Substitute Algorithm* (195).

Encapsulate Record

formerly: *Replace Record with Data Class*



```
organization = {name: "Acme Gooseberries", country: "GB"};
```



```
class Organization {
  constructor(data) {
    this._name = data.name;
    this._country = data.country;
  }
  get name() {return this._name;}
  set name(arg) {this._name = arg;}
  get country() {return this._country;}
  set country(arg) {this._country = arg;}
}
```

Motivation

This is why I often favor objects over records for mutable data. With objects, I can hide what is stored and provide methods for all three values. The user of the object doesn't need to know or care which is stored and which is calculated. This encapsulation also helps with renaming: I can rename the field while providing methods for both the new and the old names, gradually updating callers until they are all done.

I just said I favor objects for *mutable* data. If I have an immutable value, I can just have all three values in my record, using an enrichment step if necessary. Similarly, it's easy to copy the field when renaming.

I can have two kinds of record structures: those where I declare the legal field names and those that allow me to use whatever I like. The latter are often implemented through a library class called something like hash, map, hashmap, dictionary, or associative array. Many languages provide convenient syntax for creating hashmaps, which makes them useful in many programming situations. The downside of using them is they are aren't explicit about their fields. The only

way I can tell if they use start/end or start/length is by looking at where they are created and used. This isn't a problem if they are only used in a small section of a program, but the wider their scope of usage, the greater problem I get from their implicit structure. I could refactor such implicit records into explicit ones—but if I need to do that, I'd rather make them classes instead.

It's common to pass nested structures of lists and hashmaps which are often serialized into formats like JSON or XML. Such structures can be encapsulated too, which helps if their formats change later on or if I'm concerned about updates to the data that are hard to keep track of.

Mechanics

- Use *Encapsulate Variable (132)* on the variable holding the record.

Give the functions that encapsulate the record names that are easily searchable.

- Replace the content of the variable with a simple class that wraps the record. Define an accessor inside this class that returns the raw record. Modify the functions that encapsulate the variable to use this accessor.
- Test.
- Provide new functions that return the object rather than the raw record.
- For each user of the record, replace its use of a function that returns the record with a function that returns the object. Use an accessor on the object to get at the field data, creating that accessor if needed. Test after each change.

If it's a complex record, such as one with a nested structure, focus on clients that update the data first. Consider returning a copy or read-only proxy of the data for clients that only read the data.

- Remove the class's raw data accessor and the easily searchable functions that returned the raw record.
- Test.
- If the fields of the record are themselves structures, consider using Encapsulate Record and *Encapsulate Collection (170)* recursively.

Example

I'll start with a constant that is widely used across a program.

```
const organization = {name: "Acme Gooseberries", country: "GB"};
```

This is a JavaScript object which is being used as a record structure by various parts of the program, with accesses like this:

```
result += `<h1>${organization.name}</h1>`;
```

and

```
organization.name = newName;
```

The first step is a simple *Encapsulate Variable (132)*.

```
function getRawDataOfOrganization() {return organization;}
```

example reader...

```
result += `<h1>${getRawDataOfOrganization().name}</h1>`;
```

example writer...

```
getRawDataOfOrganization().name = newName;
```

It's not quite a standard *Encapsulate Variable (132)*, since I gave the getter a name deliberately chosen to be both ugly and easy to search for. This is because I intend its life to be short.

Encapsulating a record means going deeper than just the variable itself; I want to control how it's manipulated. I can do this by replacing the record with a class.

class Organization...

```
class Organization {
  constructor(data) {
    this._data = data;
  }
}
```

top level

```
const organization = new Organization({name: "Acme Gooseberries", country: "GB"});

function getRawDataOfOrganization() {return organization._data;}
function getOrganization() {return organization;}
```

Now that I have an object in place, I start looking at the users of the record. Any one that updates the record gets replaced with a setter.

class Organization...

```
set name(aString) {this._data.name = aString;}
```

client...

```
getOrganization().name = newName;
```

Similarly, I replace any readers with the appropriate getter.

class Organization...

```
get name() {return this._data.name;}
```

client...

```
result += `<h1>${getOrganization().name}</h1>`;
```

After I've done that, I can follow through on my threat to give the ugly sounding function a short life.

```
function getRawDataOfOrganization() {return organization._data;}  
function getOrganization() {return organization;}
```

I'd also be inclined to fold the `_data` field directly into the object.

```
class Organization {  
  constructor(data) {  
    this._name = data.name;  
    this._country = data.country;  
  }  
  get name() {return this._name;}  
  set name(aString) {this._name = aString;}  
  get country() {return this._country;}  
  set country(aCountryCode) {this._country = aCountryCode;}  
}
```

This has the advantage of breaking the link to the input data record. This might be useful if a reference to it runs around, which would break encapsulation. Should I not fold the data into individual fields, I would be wise to copy `_data` when I assign it.

Example: Encapsulating a Nested Record

The above example looks at a shallow record, but what do I do with data that is deeply nested, e.g., coming from a JSON document? The core refactoring steps still apply, and I have to be equally careful with updates, but I do get some options around reads.

As an example, here is some slightly more nested data: a collection of customers, kept in a hashmap indexed by their customer ID.

```

"1920": {
  name: "martin",
  id: "1920",
  usages: {
    "2016": {
      "1": 50,
      "2": 55,
      // remaining months of the year
    },
    "2015": {
      "1": 70,
      "2": 63,
      // remaining months of the year
    }
  },
},
"38673": {
  name: "neal",
  id: "38673",
  // more customers in a similar form

```

With more nested data, reads and writes can be digging into the data structure.

sample update...

```
customerData[customerID].usages[year][month] = amount;
```

sample read...

```

function compareUsage (customerID, laterYear, month) {
  const later = customerData[customerID].usages[laterYear][month];
  const earlier = customerData[customerID].usages[laterYear - 1][month];
  return {laterAmount: later, change: later - earlier};
}

```

To encapsulate this data, I also start with *Encapsulate Variable (132)*.

```

function getRawDataOfCustomers() {return customerData;}
function setRawDataOfCustomers(arg) {customerData = arg;}

```

sample update...

```
getRawDataOfCustomers()[customerID].usages[year][month] = amount;
```

sample read...

```

function compareUsage (customerID, laterYear, month) {
  const later = getRawDataOfCustomers()[customerID].usages[laterYear][month];
  const earlier = getRawDataOfCustomers()[customerID].usages[laterYear - 1][month];
  return {laterAmount: later, change: later - earlier};
}

```

I then make a class for the overall data structure.

```
class CustomerData {
  constructor(data) {
    this._data = data;
  }
}
```

top level...

```
function getCustomerData() {return customerData;}
function getRawDataOfCustomers() {return customerData._data;}
function setRawDataOfCustomers(arg) {customerData = new CustomerData(arg);}
```

The most important area to deal with is the updates. So, while I look at all the callers of `getRawDataOfCustomers`, I'm focused on those where the data is changed. To remind you, here's the update again:

sample update...

```
getRawDataOfCustomers()[customerID].usages[year][month] = amount;
```

The general mechanics now say to return the full customer and use an accessor, creating one if needed. I don't have a setter on the customer for this update, and this one digs into the structure. So, to make one, I begin by using *Extract Function (106)* on the code that digs into the data structure.

sample update...

```
setUsage(customerID, year, month, amount);
```

top level...

```
function setUsage(customerID, year, month, amount) {
  getRawDataOfCustomers()[customerID].usages[year][month] = amount;
}
```

I then use *Move Function (198)* to move it into the new customer data class.

sample update...

```
getCustomerData().setUsage(customerID, year, month, amount);
```

class CustomerData...

```
setUsage(customerID, year, month, amount) {
  this._data[customerID].usages[year][month] = amount;
}
```

When working with a big data structure, I like to concentrate on the updates. Getting them visible and gathered in a single place is the most important part of the encapsulation.

At some point, I will think I've got them all—but how can I be sure? There's a couple of ways to check. One is to modify `getRawDataOfCustomers` to return a deep copy of the data; if my test coverage is good, one of the tests should break if I missed a modification.

top level...

```
function getCustomerData() {return customerData;}
function getRawDataOfCustomers() {return customerData.rawData;}
function setRawDataOfCustomers(arg) {customerData = new CustomerData(arg);}
```

class CustomerData...

```
get rawData() {
  return _.cloneDeep(this._data);
}
```

I'm using the *lodash* library to make a deep copy.

Another approach is to return a read-only proxy for the data structure. Such a proxy could raise an exception if the client code tries to modify the underlying object. Some languages make this easy, but it's a pain in JavaScript, so I'll leave it as an exercise for the reader. I could also take a copy and recursively freeze it to detect any modifications.

Dealing with the updates is valuable, but what about the readers? Here there are a few options.

The first option is to do the same thing as I did for the setters. Extract all the reads into their own functions and move them into the customer data class.

class CustomerData...

```
usage(customerID, year, month) {
  return this._data[customerID].usages[year][month];
}
```

top level...

```
function compareUsage (customerID, laterYear, month) {
  const later = getCustomerData().usage(customerID, laterYear, month);
  const earlier = getCustomerData().usage(customerID, laterYear - 1, month);
  return {laterAmount: later, change: later - earlier};
}
```

The great thing about this approach is that it gives *customerData* an explicit API that captures all the uses made of it. I can look at the class and see all their uses of the data. But this can be a lot of code for lots of special cases. Modern languages provide good affordances for digging into a list-and-hash [mf-lh] data structure, so it's useful to give clients just such a data structure to work with.

If the client wants a data structure, I can just hand out the actual data. But the problem with this is that there's no way to prevent clients from modifying the data directly, which breaks the whole point of encapsulating all the updates inside functions. Consequently, the simplest thing to do is to provide a copy of the underlying data, using the *rawData* method I wrote earlier.

```
class CustomerData...
```

```
  get rawData() {  
    return _.cloneDeep(this._data);  
  }
```

```
top level...
```

```
function compareUsage (customerID, laterYear, month) {  
  const later  = getCustomerData().rawData[customerID].usages[laterYear][month];  
  const earlier = getCustomerData().rawData[customerID].usages[laterYear - 1][month];  
  return {laterAmount: later, change: later - earlier};  
}
```

But although it's simple, there are downsides. The most obvious problem is the cost of copying a large data structure, which may turn out to be a performance problem. As with anything like this, however, the performance cost might be acceptable—I would want to measure its impact before I start to worry about it. There may also be confusion if clients expect modifying the copied data to modify the original. In those cases, a read-only proxy or freezing the copied data might provide a helpful error should they do this.

Another option is more work, but offers the most control: Apply Encapsulate Record recursively. With this, I turn the customer record into its own class, apply *Encapsulate Collection* (170) to the usages, and create a usage class. I can then enforce control of updates by using accessors, perhaps applying *Change Reference to Value* (252) on the usage objects. But this can be a lot of effort for a large data structure—and not really needed if I don't access that much of the data structure. Sometimes, a judicious mix of getters and new classes may work, using a getter to dig deep into the structure but returning an object that wraps the structure rather than the unencapsulated data. I wrote about this kind of thing in an article "Refactoring Code to Load a Document" [mf-ref-doc].

Encapsulate Collection



```
class Person {  
    get courses() {return this._courses;}  
    set courses(aList) {this._courses = aList;}  
}
```



```
class Person {  
    get courses() {return this._courses.slice();}  
    addCourse(aCourse) { ... }  
    removeCourse(aCourse) { ... }  
}
```

Motivation

I like encapsulating any mutable data in my programs. This makes it easier to see when and how data structures are modified, which then makes it easier to change those data structures when I need to. Encapsulation is often encouraged, particularly by object-oriented developers, but a common mistake occurs when working with collections. Access to a collection variable may be encapsulated, but if the getter returns the collection itself, then that collection's membership can be altered without the enclosing class being able to intervene.

To avoid this, I provide collection modifier methods—usually `add` and `remove`—on the class itself. This way, changes to the collection go through the owning class, giving me the opportunity to modify such changes as the program evolves.

If the team has the habit of not to modify collections outside the original module, just providing these methods may be enough. However, it's usually unwise to rely on such habits; a mistake here can lead to bugs that are difficult to track down later. A better approach is to ensure that the getter for the collection does not return the raw collection, so that clients cannot accidentally change it.

One way to prevent modification of the underlying collection is by never returning a collection value. In this approach, any use of a collection field is done with specific methods on the owning class, replacing `aCustomer.orders.size` with `aCustomer.numberOfOrders`. I don't agree with this approach. Modern languages have rich collection classes with standardized interfaces, which can be combined

in useful ways such as Collection Pipelines [mf-cp]. Putting in special methods to handle this kind of functionality adds a lot of extra code and cripples the easy composability of collection operations.

Another way is to allow some form of read-only access to a collection. Java, for example, makes it easy to return a read-only proxy to the collection. Such a proxy forwards all reads to the underlying collection, but blocks all writes—in Java’s case, throwing an exception. A similar route is used by libraries that base their collection composition on some kind of iterator or enumerable object—providing that iterator cannot modify the underlying collection.

Probably the most common approach is to provide a getting method for the collection, but make it return a copy of the underlying collection. That way, any modifications to the copy don’t affect the encapsulated collection. This might cause some confusion if programmers expect the returned collection to modify the source field—but in many code bases, programmers are used to collection getters providing copies. If the collection is huge, this may be a performance issue—but most lists aren’t all that big, so the general rules for performance should apply (*Refactoring and Performance* (64)).

Another difference between using a proxy and a copy is that a modification of the source data will be visible in the proxy but not in a copy. This isn’t an issue most of the time, because lists accessed in this way are usually only held for a short time.

What’s important here is consistency within a code base. Use only one mechanism so everyone can get used to how it behaves and expect it when calling any collection accessor function.

Mechanics

- Apply *Encapsulate Variable* (132) if the reference to the collection isn’t already encapsulated.
- Add functions to add and remove elements from the collection.
 - If there is a setter for the collection, use *Remove Setting Method* (331) if possible. If not, make it take a copy of the provided collection.
- Run static checks.
- Find all references to the collection. If anyone calls modifiers on the collection, change them to use the new add/remove functions. Test after each change.
- Modify the getter for the collection to return a protected view on it, using a read-only proxy or a copy.
- Test.

Example

I start with a person class that has a field for a list of courses.

class Person...

```
    constructor (name) {
        this._name = name;
        this._courses = [];
    }
    get name() {return this._name;}
    get courses() {return this._courses;}
    set courses(aList) {this._courses = aList;}
```

class Course...

```
    constructor(name, isAdvanced) {
        this._name = name;
        this._isAdvanced = isAdvanced;
    }
    get name() {return this._name;}
    get isAdvanced() {return this._isAdvanced;}
```

Clients use the course collection to gather information on courses.

```
numAdvancedCourses = aPerson.courses
    .filter(c => c.isAdvanced)
    .length
;
```

A naive developer would say this class has proper data encapsulation: After all, each field is protected by accessor methods. But I would argue that the list of courses isn't properly encapsulated. Certainly, anyone updating the courses as a single value has proper control through the setter:

client code...

```
const basicCourseNames = readBasicCourseNames(filename);
aPerson.courses = basicCourseNames.map(name => new Course(name, false));
```

But clients might find it easier to update the course list directly.

client code...

```
for(const name of readBasicCourseNames(filename)) {
    aPerson.courses.push(new Course(name, false));
}
```

This violates encapsulating because the person class has no ability to take control when the list is updated in this way. While the reference to the field is encapsulated, the content of the field is not.

I'll begin creating proper encapsulation by adding methods to the person class that allow a client to add and remove individual courses.

class Person...

```
addCourse(aCourse) {
  this._courses.push(aCourse);
}
removeCourse(aCourse, fnIfAbsent = () => {throw new RangeError();}) {
  const index = this._courses.indexOf(aCourse);
  if (index === -1) fnIfAbsent();
  else this._courses.splice(index, 1);
}
```

With a removal, I have to decide what to do if a client asks to remove an element that isn't in the collection. I can either shrug, or raise an error. With this code, I default to raising an error, but give the callers an opportunity to do something else if they wish.

I then change any code that calls modifiers directly on the collection to use new methods.

client code...

```
for(const name of readBasicCourseNames(filename)) {
  aPerson.addCourse(new Course(name, false));
}
```

With individual add and remove methods, there is usually no need for `setCourses`, in which case I'll use *Remove Setting Method (331)* on it. Should the API need a setting method for some reason, I ensure it puts a copy of the collection in the field.

class Person...

```
set courses(aList) {this._courses = aList.slice();}
```

All this enables the clients to use the right kind of modifier methods, but I prefer to ensure nobody modifies the list without using them. I can do this by providing a copy.

class Person...

```
get courses() {return this._courses.slice();}
```

In general, I find it wise to be moderately paranoid about collections and I'd rather copy them unnecessarily than debug errors due to unexpected modifications. Modifications aren't always obvious; for example, sorting an array in JavaScript modifies the original, while many languages default to making a copy for an operation that changes a collection. Any class that's responsible for managing a collection should always give out copies—but I also get into the habit of making a copy if I do something that's liable to change a collection.

Replace Primitive with Object

formerly: *Replace Data Value with Object*

formerly: *Replace Type Code with Class*



```
orders.filter(o => "high" === o.priority
    || "rush" === o.priority);
```



```
orders.filter(o => o.priority.higherThan(new Priority("normal")))
```

Motivation

Often, in early stages of development you make decisions about representing simple facts as simple data items, such as numbers or strings. As development proceeds, those simple items aren't so simple anymore. A telephone number may be represented as a string for a while, but later it will need special behavior for formatting, extracting the area code, and the like. This kind of logic can quickly end up being duplicated around the code base, increasing the effort whenever it needs to be used.

As soon as I realize I want to do something other than simple printing, I like to create a new class for that bit of data. At first, such a class does little more than wrap the primitive—but once I have that class, I have a place to put behavior specific to its needs. These little values start very humble, but once nurtured they can grow into useful tools. They may not look like much, but I find their effects on a code base can be surprisingly large. Indeed many experienced developers consider this to be one of the most valuable refactorings in the toolkit—even though it often seems counterintuitive to a new programmer.

Mechanics

- Apply *Encapsulate Variable (132)* if it isn't already.
- Create a simple value class for the data value. It should take the existing value in its constructor and provide a getter for that value.
- Run static checks.
- Change the setter to create a new instance of the value class and store that in the field, changing the type of the field if present.
- Change the getter to return the result of invoking the getter of the new class.
- Test.
- Consider using *Rename Function (124)* on the original accessors to better reflect what they do.
- Consider clarifying the role of the new object as a value or reference object by applying *Change Reference to Value (252)* or *Change Value to Reference (256)*.

Example

I begin with a simple order class that reads its data from a simple record structure. One of its properties is a priority, which it reads as a simple string.

```
class Order...
  constructor(data) {
    this.priority = data.priority;
    // more initialization
```

Some client codes uses it like this:

```
client...
  highPriorityCount = orders.filter(o => "high" === o.priority
                                     || "rush" === o.priority)
                           .length;
```

Whenever I'm fiddling with a data value, the first thing I do is use *Encapsulate Variable (132)* on it.

```
class Order...
  get priority()      {return this._priority;}
  set priority(aString) {this._priority = aString;}
```

The constructor line that initializes the priority will now use the setter I define here.

This self-encapsulates the field so I can preserve its current use while I manipulate the data itself.

I create a simple value class for the priority. It has a constructor for the value and a conversion function to return a string.

```
class Priority {
  constructor(value) {this._value = value;}
  toString() {return this._value;}
}
```

I prefer using a conversion function (`toString`) rather than a getter (`value`) here. For clients of the class, asking for the string representation should feel more like a conversion than getting a property.

I then modify the accessors to use this new class.

class Order...

```
get priority()      {return this._priority.toString();}
set priority(aString) {this._priority = new Priority(aString);}
```

Now that I have a priority class, I find the current getter on the order to be misleading. It doesn't return the priority—but a string that describes the priority. My immediate move is to use *Rename Function (124)*.

class Order...

```
get priorityString() {return this._priority.toString();}
set priority(aString) {this._priority = new Priority(aString);}
```

client...

```
highPriorityCount = orders.filter(o => "high" === o.priorityString
                                     || "rush" === o.priorityString)
  .length;
```

In this case, I'm happy to retain the name of the setter. The name of the argument communicates what it expects.

Now I'm done with the formal refactoring. But as I look at who uses the priority, I consider whether they should use the priority class themselves. As a result, I provide a getter on order that provides the new priority object directly.

class Order...

```
get priority()      {return this._priority;}
get priorityString() {return this._priority.toString();}
set priority(aString) {this._priority = new Priority(aString);}
```

client...

```
highPriorityCount = orders.filter(o => "high" === o.priority.toString()
                                     || "rush" === o.priority.toString())
  .length;
```

As the priority class becomes useful elsewhere, I would allow clients of the order to use the setter with a priority instance, which I do by adjusting the priority constructor.

class Priority...

```
constructor(value) {
  if (value instanceof Priority) return value;
  this._value = value;
}
```

The point of all this is that now, my new priority class can be useful as a place for new behavior—either new to the code or moved from elsewhere. Here's some simple code to add validation of priority values and comparison logic:

class Priority...

```
constructor(value) {
  if (value instanceof Priority) return value;
  if (Priority.legalValues().includes(value))
    this._value = value;
  else
    throw new Error(`<${value}> is invalid for Priority`);
}
toString() {return this._value;}
get _index() {return Priority.legalValues().findIndex(s => s === this._value);}
static legalValues() {return ['low', 'normal', 'high', 'rush'];}

equals(other) {return this._index === other._index;}
higherThan(other) {return this._index > other._index;}
lowerThan(other) {return this._index < other._index;}
```

As I do this, I decide that a priority should be a value object, so I provide an equals method and ensure that it is immutable.

Now I've added that behavior, I can make the client code more meaningful:

client...

```
highPriorityCount = orders.filter(o => o.priority.higherThan(new Priority("normal")))
  .length;
```

Replace Temp with Query



```
const basePrice = this._quantity * this._itemPrice;  
if (basePrice > 1000)  
  return basePrice * 0.95;  
else  
  return basePrice * 0.98;
```



```
get basePrice() {this._quantity * this._itemPrice;}  
  
...  
  
if (this.basePrice > 1000)  
  return this.basePrice * 0.95;  
else  
  return this.basePrice * 0.98;
```

Motivation

One use of temporary variables is to capture the value of some code in order to refer to it later in a function. Using a temp allows me to refer to the value while explaining its meaning and avoiding repeating the code that calculates it. But while using a variable is handy, it can often be worthwhile to go a step further and use a function instead.

If I'm working on breaking up a large function, turning variables into their own functions makes it easier to extract parts of the function, since I no longer need

to pass in variables into the extracted functions. Putting this logic into functions often also sets up a stronger boundary between the extracted logic and the original function, which helps me spot and avoid awkward dependencies and side effects.

Using functions instead of variables also allows me to avoid duplicating the calculation logic in similar functions. Whenever I see variables calculated in the same way in different places, I look to turn them into a single function.

This refactoring works best if I'm inside a class, since the class provides a shared context for the methods I'm extracting. Outside of a class, I'm liable to have too many parameters in a top-level function which negates much of the benefit of using a function. Nested functions can avoid this, but they limit my ability to share the logic between related functions.

Only some temporary variables are suitable for Replace Temp with Query. The variable needs to be calculated once and then only be read afterwards. In the simplest case, this means the variable is assigned to once, but it's also possible to have several assignments in a more complicated lump of code—all of which has to be extracted into the query. Furthermore, the logic used to calculate the variable must yield the same result when the variable is used later—which rules out variables used as snapshots with names like `oldAddress`.

Mechanics

- Check that the variable is determined entirely before it's used, and the code that calculates it does not yield a different value whenever it is used.
- If the variable isn't read-only, and can be made read-only, do so.
- Test.
- Extract the assignment of the variable into a function.

If the variable and the function cannot share a name, use a temporary name for the function.

Ensure the extracted function is free of side effects. If not, use *Separate Query from Modifier* (306).

- Test.
- Use *Inline Variable* (123) to remove the temp.

Example

Here is a simple class:

```
class Order...
  constructor(quantity, item) {
    this._quantity = quantity;
    this._item = item;
  }

  get price() {
    var basePrice = this._quantity * this._item.price;
    var discountFactor = 0.98;
    if (basePrice > 1000) discountFactor -= 0.03;
    return basePrice * discountFactor;
  }
}
```

I want to replace the temps `basePrice` and `discountFactor` with methods.

Starting with `basePrice`, I make it `const` and run tests. This is a good way of checking that I haven't missed a reassignment—unlikely in such a short function but common when I'm dealing with something larger.

```
class Order...
  constructor(quantity, item) {
    this._quantity = quantity;
    this._item = item;
  }

  get price() {
    const basePrice = this._quantity * this._item.price;
    var discountFactor = 0.98;
    if (basePrice > 1000) discountFactor -= 0.03;
    return basePrice * discountFactor;
  }
}
```

I then extract the right-hand side of the assignment to a getting method.

```
class Order...
  get price() {
    const basePrice = this.basePrice;
    var discountFactor = 0.98;
    if (basePrice > 1000) discountFactor -= 0.03;
    return basePrice * discountFactor;
  }

  get basePrice() {
    return this._quantity * this._item.price;
  }
}
```

I test, and apply *Inline Variable (123)*.

class Order...

```
get price() {  
  const basePrice = this.basePrice;  
  var discountFactor = 0.98;  
  if (this.basePrice > 1000) discountFactor -= 0.03;  
  return this.basePrice * discountFactor;  
}
```

I then repeat the steps with discountFactor, first using *Extract Function (106)*.

class Order...

```
get price() {  
  const discountFactor = this.discountFactor;  
  return this.basePrice * discountFactor;  
}  
  
get discountFactor() {  
  var discountFactor = 0.98;  
  if (this.basePrice > 1000) discountFactor -= 0.03;  
  return discountFactor;  
}
```

In this case I need my extracted function to contain both assignments to discountFactor. I can also set the original variable to be const.

Then, I inline:

```
get price() {  
  return this.basePrice * this.discountFactor;  
}
```

Extract Class

inverse of: *Inline Class* (186)



```
class Person {  
    get officeAreaCode() {return this._officeAreaCode;}  
    get officeNumber()   {return this._officeNumber;}  
}
```



```
class Person {  
    get officeAreaCode() {return this._telephoneNumber.areaCode;}  
    get officeNumber()   {return this._telephoneNumber.number;}  
}  
class TelephoneNumber {  
    get areaCode() {return this._areaCode;}  
    get number()   {return this._number;}  
}
```

Motivation

You’ve probably read guidelines that a class should be a crisp abstraction, only handle a few clear responsibilities, and so on. In practice, classes grow. You add some operations here, a bit of data there. You add a responsibility to a class feeling that it’s not worth a separate class—but as that responsibility grows and breeds, the class becomes too complicated. Soon, your class is as crisp as a microwaved duck.

Imagine a class with many methods and quite a lot of data. A class that is too big to understand easily. You need to consider where it can be split—and split it. A good sign is when a subset of the data and a subset of the methods seem to go together. Other good signs are subsets of data that usually change together or are particularly dependent on each other. A useful test is to ask yourself what would happen if you remove a piece of data or a method. What other fields and methods would become nonsense?

One sign that often crops up later in development is the way the class is subtyped. You may find that subtyping affects only a few features or that some features need to be subtyped one way and other features a different way.

Mechanics

- Decide how to split the responsibilities of the class.
- Create a new child class to express the split-off responsibilities.
 - If the responsibilities of the original parent class no longer match its name, rename the parent.
- Create an instance of the child class when constructing the parent and add a link from parent to child.
- Use *Move Field (207)* on each field you wish to move. Test after each move.
- Use *Move Function (198)* to move methods to the new child. Start with lower-level methods (those being called rather than calling). Test after each move.
- Review the interfaces of both classes, remove unneeded methods, change names to better fit the new circumstances.
- Decide whether to expose the new child. If so, consider applying *Change Reference to Value (252)* to the child class.

Example

I start with a simple person class:

class Person...

```
get name() {return this._name;}
set name(arg) {this._name = arg;}
get telephoneNumber() {return `${this.officeAreaCode} ${this.officeNumber}`;}
get officeAreaCode() {return this._officeAreaCode;}
set officeAreaCode(arg) {this._officeAreaCode = arg;}
get officeNumber() {return this._officeNumber;}
set officeNumber(arg) {this._officeNumber = arg;}
```

Here, I can separate the telephone number behavior into its own class. I start by defining an empty telephone number class:

```
class TelephoneNumber {
}
```

That was easy! Next, I create an instance of telephone number when constructing the person:

class Person...

```
constructor() {
  this._telephoneNumber = new TelephoneNumber();
}
```

class TelephoneNumber...

```
get officeAreaCode() {return this._officeAreaCode;}
set officeAreaCode(arg) {this._officeAreaCode = arg;}
```

I then use *Move Field (207)* on one of the fields.

class Person...

```
get officeAreaCode() {return this._telephoneNumber.officeAreaCode;}
set officeAreaCode(arg) {this._telephoneNumber.officeAreaCode = arg;}
```

I test, then move the next field.

class TelephoneNumber...

```
get officeNumber() {return this._officeNumber;}
set officeNumber(arg) {this._officeNumber = arg;}
```

class Person...

```
get officeNumber() {return this._telephoneNumber.officeNumber;}
set officeNumber(arg) {this._telephoneNumber.officeNumber = arg;}
```

Test again, then move the telephone number method.

class TelephoneNumber...

```
get telephoneNumber() {return `(${this.officeAreaCode}) ${this.officeNumber}`;}
```

class Person...

```
get telephoneNumber() {return this._telephoneNumber.telephoneNumber;}
```

Now I should tidy things up. Having “office” as part of the telephone number code makes no sense, so I rename them.

class TelephoneNumber...

```
get areaCode() {return this._areaCode;}
set areaCode(arg) {this._areaCode = arg;}

get number() {return this._number;}
set number(arg) {this._number = arg;}
```

class Person...

```
get officeAreaCode() {return this._telephoneNumber.areaCode;}
set officeAreaCode(arg) {this._telephoneNumber.areaCode = arg;}
get officeNumber() {return this._telephoneNumber.number;}
set officeNumber(arg) {this._telephoneNumber.number = arg;}
```

The telephone number method on the telephone number class also doesn’t make much sense, so I apply *Rename Function (124)*.

class TelephoneNumber...

```
toString() {return `(${this.areaCode}) ${this.number}`;}
```

```
class Person...  
    get telephoneNumber() {return this._telephoneNumber.toString();}
```

Telephone numbers are generally useful, so I think I'll expose the new object to clients. I can replace those "office" methods with accessors for the telephone number. But this way, the telephone number will work better as a Value Object [mf-vo], so I would apply *Change Reference to Value (252)* first (that refactoring's example shows how I'd do that for the telephone number).

Inline Class

inverse of: *Extract Class* (182)



```
class Person {  
    get officeAreaCode() {return this._telephoneNumber.areaCode;}  
    get officeNumber() {return this._telephoneNumber.number;}  
}  
class TelephoneNumber {  
    get areaCode() {return this._areaCode;}  
    get number() {return this._number;}  
}
```



```
class Person {  
    get officeAreaCode() {return this._officeAreaCode;}  
    get officeNumber() {return this._officeNumber;}  
}
```

Motivation

Inline Class is the inverse of *Extract Class* (182). I use Inline Class if a class is no longer pulling its weight and shouldn't be around any more. Often, this is the result of refactoring that moves other responsibilities out of the class so there is little left. At that point, I fold the class into another—one that makes most use of the runt class.

Another reason to use Inline Class is if I have two classes that I want to refactor into a pair of classes with a different allocation of features. I may find it easier to first use Inline Class to combine them into a single class, then *Extract Class* (182) to make the new separation. This is a general approach when reorganizing things: Sometimes, it's easier to move elements one at a time from one context to another, but sometimes it's better to use an inline refactoring to collapse the contexts together, then use an extract refactoring to separate them into different elements.

Mechanics

- In the target class, create functions for all the public functions of the source class. These functions should just delegate to the source class.
- Change all references to source class methods so they use the target class's delegators instead. Test after each change.
- Move all the functions and data from the source class into the target, testing after each move, until the source class is empty.
- Delete the source class and hold a short, simple funeral service.

Example

Here's a class that holds a couple of pieces of tracking information for a shipment.

```
class TrackingInformation {
  get shippingCompany() {return this._shippingCompany;}
  set shippingCompany(arg) {this._shippingCompany = arg;}
  get trackingNumber() {return this._trackingNumber;}
  set trackingNumber(arg) {this._trackingNumber = arg;}
  get display() {
    return `${this.shippingCompany}: ${this.trackingNumber}`;
  }
}
```

It's used as part of a shipment class.

class Shipment...

```
  get trackingInfo() {
    return this._trackingInformation.display;
  }
  get trackingInformation() {return this._trackingInformation;}
  set trackingInformation(aTrackingInformation) {
    this._trackingInformation = aTrackingInformation;
  }
}
```

While this class may have been worthwhile in the past, I no longer feel it's pulling its weight, so I want to inline it into Shipment.

I start by looking at places that are invoking the methods of TrackingInformation.

caller...

```
aShipment.trackingInformation.shippingCompany = request.vendor;
```

I'm going to move all such functions to Shipment, but I do it slightly differently to how I usually do *Move Function* (198). In this case, I start by putting a delegating method into the shipment, and adjusting the client to call that.

class Shipment...

```
set shippingCompany(arg) {this._trackingInformation.shippingCompany = arg;}
```

caller...

```
aShipment.trackingInformation.shippingCompany = request.vendor;
```

I do this for all the elements of tracking information that are used by clients. Once I've done that, I can move all the elements of the tracking information over into the shipment class.

I start by applying *Inline Function (115)* to the display method.

class Shipment...

```
get trackingInfo() {
  return `${this.shippingCompany}: ${this.trackingNumber}`;
}
```

I move the shipping company field.

```
get shippingCompany() {return this._trackingInformation.shippingCompany;}
set shippingCompany(arg) {this._trackingInformation.shippingCompany = arg;}
```

I don't use the full mechanics for *Move Field (207)* since in this case I only reference shippingCompany from Shipment which is the target of the move. I thus don't need the steps that put a reference from the source to the target.

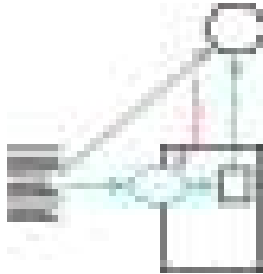
I continue until everything is moved over. Once I've done that, I can delete the tracking information class.

class Shipment...

```
get trackingInfo() {
  return `${this.shippingCompany}: ${this.trackingNumber}`;
}
get shippingCompany() {return this._shippingCompany;}
set shippingCompany(arg) {this._shippingCompany = arg;}
get trackingNumber() {return this._trackingNumber;}
set trackingNumber(arg) {this._trackingNumber = arg;}
```

Hide Delegate

inverse of: *Remove Middle Man* (192)



```
manager = aPerson.department.manager;
```



```
manager = aPerson.manager;

class Person {
    get manager() {return this.department.manager;}
```

Motivation

One of the keys—if not *the* key—to good modular design is encapsulation. Encapsulation means that modules need to know less about other parts of the system. Then, when things change, fewer modules need to be told about the change—which makes the change easier to make.

When we are first taught about object orientation, we are told that encapsulation means hiding our fields. As we become more sophisticated, we realize there is more that we can encapsulate.

If I have some client code that calls a method defined on an object in a field of a server object, the client needs to know about this delegate object. If the delegate changes its interface, changes propagate to all the clients of the server that use the delegate. I can remove this dependency by placing a simple delegating method on the server that hides the delegate. Then any changes I make to the delegate propagate only to the server and not to the clients.



Mechanics

- For each method on the delegate, create a simple delegating method on the server.
- Adjust the client to call the server. Test after each change.
- If no client needs to access the delegate anymore, remove the server's accessor for the delegate.
- Test.

Example

I start with a person and a department.

class Person...

```

constructor(name) {
    this._name = name;
}
get name() {return this._name;}
get department() {return this._department;}
set department(arg) {this._department = arg;}
  
```

class Department...

```

get chargeCode() {return this._chargeCode;}
set chargeCode(arg) {this._chargeCode = arg;}
get manager() {return this._manager;}
set manager(arg) {this._manager = arg;}
  
```

Some client code wants to know the manager of a person. To do this, it needs to get the department first.

client code...

```

manager = aPerson.department.manager;
  
```

This reveals to the client how the department class works and that the department is responsible for tracking the manager. I can reduce this coupling by

hiding the department class from the client. I do this by creating a simple delegating method on person:

class Person...

```
    get manager() {return this._department.manager;}
```

I now need to change all clients of person to use this new method:

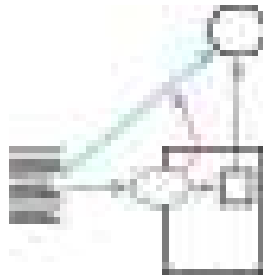
client code...

```
manager = aPerson-department.manager;
```

Once I've made the change for all methods of department and for all the clients of person, I can remove the department accessor on person.

Remove Middle Man

inverse of: *Hide Delegate* (189)



```
manager = aPerson.manager;  
  
class Person {  
    get manager() {return this.department.manager;}  
}
```



```
manager = aPerson.department.manager;
```

Motivation

In the motivation for *Hide Delegate* (189), I talked about the advantages of encapsulating the use of a delegated object. There is a price for this. Every time the client wants to use a new feature of the delegate, I have to add a simple delegating method to the server. After adding features for a while, I get irritated with all this forwarding. The server class is just a middle man (*Middle Man* (81)), and perhaps it's time for the client to call the delegate directly. (This smell often pops up when people get overenthusiastic about following the Law of Demeter, which I'd like a lot more if it were called the Occasionally Useful Suggestion of Demeter.)

It's hard to figure out what the right amount of hiding is. Fortunately, with *Hide Delegate* (189) and Remove Middle Man, it doesn't matter so much. I can adjust my code as time goes on. As the system changes, the basis for how much I hide also changes. A good encapsulation six months ago may be awkward now. Refactoring means I never have to say I'm sorry—I just fix it.

Mechanics

- Create a getter for the delegate.
- For each client use of a delegating method, replace the call to the delegating method by chaining through the accessor. Test after each replacement.

If all calls to a delegating method are replaced, you can delete the delegating method.

With automated refactorings, you can use *Encapsulate Variable* (132) on the delegate field and then *Inline Function* (115) on all the methods that use it.

Example

I begin with a person class that uses a linked department object to determine a manager. (If you're reading this book sequentially, this example may look eerily familiar.)

client code...

```
manager = aPerson.manager;
```

class Person...

```
get manager() {return this._department.manager;}
```

class Department...

```
get manager()    {return this._manager;}
```

This is simple to use and encapsulates the department. However, if lots of methods are doing this, I end up with too many of these simple delegations on the person. That's when it is good to remove the middle man. First, I make an accessor for the delegate:

class Person...

```
get department() {return this._department;}
```

Now I go to each client at a time and modify them to use the department directly.

client code...

```
manager = aPerson.department.manager;
```

Once I've done this with all the clients, I can remove the manager method from Person. I can repeat this process for any other simple delegations on Person.

I can do a mixture here. Some delegations may be so common that I'd like to keep them to make client code easier to work with. There is no absolute reason why I should either hide a delegate or remove a middle man—particular circumstances suggest which approach to take, and reasonable people can differ on what works best.

If I have automated refactorings, then there's a useful variation on these steps. First, I use *Encapsulate Variable (132)* on `department`. This changes the manager getter to use the public department getter:

class Person...

```
get manager() {return this.department.manager;}
```

The change is rather too subtle in JavaScript, but by removing the underscore from `department` I'm using the new getter rather than accessing the field directly.

Then I apply *Inline Function (115)* on the manager method to replace all the callers at once.

Substitute Algorithm



```
function foundPerson(people) {  
  for(let i = 0; i < people.length; i++) {  
    if (people[i] === "Don") {  
      return "Don";  
    }  
    if (people[i] === "John") {  
      return "John";  
    }  
    if (people[i] === "Kent") {  
      return "Kent";  
    }  
  }  
  return "";  
}
```



```
function foundPerson(people) {  
  const candidates = ["Don", "John", "Kent"];  
  return people.find(p => candidates.includes(p)) || '';  
}
```

Motivation

I've never tried to skin a cat. I'm told there are several ways to do it. I'm sure some are easier than others. So it is with algorithms. If I find a clearer way to do something, I replace the complicated way with the clearer way. Refactoring can break down something complex into simpler pieces, but sometimes I just reach the point at which I have to remove the whole algorithm and replace it with something simpler. This occurs as I learn more about the problem and realize that there's an easier way to do it. It also happens if I start using a library that supplies features that duplicate my code.

Sometimes, when I want to change the algorithm to work slightly differently, it's easier to start by replacing it with something that would make my change more straightforward to make.

When I have to take this step, I have to be sure I've decomposed the method as much as I can. Replacing a large, complex algorithm is very difficult; only by making it simple can I make the substitution tractable.

Mechanics

- Arrange the code to be replaced so that it fills a complete function.
- Prepare tests using this function only, to capture its behavior.
- Prepare your alternative algorithm.
- Run static checks.
- Run tests to compare the output of the old algorithm to the new one. If they are the same, you're done. Otherwise, use the old algorithm for comparison in testing and debugging.

Chapter 8

Moving Features

So far, the refactorings have been about creating, removing, and renaming program elements. Another important part of refactoring is moving elements between contexts. I use *Move Function* (198) to move functions between classes and other modules. Fields can move too, with *Move Field* (207).

I also move individual statements around. I use *Move Statements into Function* (213) and *Move Statements to Callers* (217) to move them in or out of functions, as well as *Slide Statements* (223) to move them within a function. Sometimes, I can take some statements that match an existing function and use *Replace Inline Code with Function Call* (222) to remove the duplication.

Two refactorings I often do with loops are *Split Loop* (227), to ensure a loop does only one thing, and *Replace Loop with Pipeline* (231) to get rid of a loop entirely.

And then there's the favorite refactoring of many a fine programmer: *Remove Dead Code* (237). Nothing is as satisfying as applying the digital flamethrower to superfluous statements.

Move Function

formerly: *Move Method*



```
class Account {  
  get overdraftCharge() {...}
```



```
class AccountType {  
  get overdraftCharge() {...}
```

Motivation

The heart of a good software design is its modularity—which is my ability to make most modifications to a program while only having to understand a small part of it. To get this modularity, I need to ensure that related software elements are grouped together and the links between them are easy to find and understand. But my understanding of how to do this isn't static—as I better understand what I'm doing, I learn how to best group together software elements. To reflect that growing understanding, I need to move elements around.

All functions live in some context; it may be global, but usually it's some form of a module. In an object-oriented program, the core modular context is a class. Nesting a function within another creates another common context. Different languages provide varied forms of modularity, each creating a context for a function to live in.

One of the most straightforward reasons to move a function is when it references elements in other contexts more than the one it currently resides in. Moving it together with those elements often improves encapsulation, allowing other parts of the software to be less dependent on the details of this module.

Similarly, I may move a function because of where its callers live, or where I need to call it from in my next enhancement. A function defined as a helper inside another function may have value on its own, so it's worth moving it to somewhere more accessible. A method on a class may be easier for me to use if shifted to another.

Deciding to move a function is rarely an easy decision. To help me decide, I examine the current and candidate contexts for that function. I need to look at what functions call this one, what functions are called by the moving function, and what data that function uses. Often, I see that I need a new context for a group of functions and create one with *Combine Functions into Class* (144) or *Extract Class* (182). Although it can be difficult to decide where the best place for a function is, the more difficult this choice, often the less it matters. I find it valuable to try working with functions in one context, knowing I'll learn how well they fit, and if they don't fit I can always move them later.

Mechanics

- Examine all the program elements used by the chosen function in its current context. Consider whether they should move too.

If I find a called function that should also move, I usually move it first. That way, moving a clusters of functions begins with the one that has the least dependency on the others in the group.

If a high-level function is the only caller of subfunctions, then you can inline those functions into the high-level method, move, and reextract at the destination.

- Check if the chosen function is a polymorphic method.

If I'm in an object-oriented language, I have to take account of super- and subclass declarations.

- Copy the function to the target context. Adjust it to fit in its new home.

If the body uses elements in the source context, I need to either pass those elements as parameters or pass a reference to that source context.

Moving a function often means I need to come up with a different name that works better in the new context.

- Perform static analysis.
- Figure out how to reference the target function from the source context.
- Turn the source function into a delegating function.
- Test.
- Consider *Inline Function* (115) on the source function.

The source function can stay indefinitely as a delegating function. But if its callers can just as easily reach the target directly, then it's better to remove the middle man.

Example: Moving a Nested Function to Top Level

I'll begin with a function that calculates the total distance for a GPS track record.

```
function trackSummary(points) {
  const totalTime = calculateTime();
  const totalDistance = calculateDistance();
  const pace = totalTime / 60 / totalDistance ;
  return {
    time: totalTime,
    distance: totalDistance,
    pace: pace
  };

  function calculateDistance() {
    let result = 0;
    for (let i = 1; i < points.length; i++) {
      result += distance(points[i-1], points[i]);
    }
    return result;
  }

  function distance(p1,p2) { ... }
  function radians(degrees) { ... }
  function calculateTime() { ... }
}
```

I'd like to move `calculateDistance` to the top level so I can calculate distances for tracks without all the other parts of the summary.

I begin by copying the function to the top level.

```
function trackSummary(points) {
  const totalTime = calculateTime();
  const totalDistance = calculateDistance();
  const pace = totalTime / 60 / totalDistance ;
  return {
    time: totalTime,
    distance: totalDistance,
    pace: pace
  };
};

function calculateDistance() {
  let result = 0;
  for (let i = 1; i < points.length; i++) {
    result += distance(points[i-1], points[i]);
  }
  return result;
}
...
```

```

function distance(p1,p2) { ... }
function radians(degrees) { ... }
function calculateTime() { ... }

}

function top_calculateDistance() {
  let result = 0;
  for (let i = 1; i < points.length; i++) {
    result += distance(points[i-1], points[i]);
  }
  return result;
}

```

When I copy a function like this, I like to change the name so I can distinguish them both in the code and in my head. I don't want to think about what the right name should be right now, so I create a temporary name.

The program still works, but my static analysis is rightly rather upset. The new function has two undefined symbols: `distance` and `points`. The natural way to deal with `points` is to pass it in as a parameter.

```

function top_calculateDistance(points) {
  let result = 0;
  for (let i = 1; i < points.length; i++) {
    result += distance(points[i-1], points[i]);
  }
  return result;
}

```

I could do the same with `distance`, but perhaps it makes sense to move it together with `calculateDistance`. Here's the relevant code:

function trackSummary...

```

function distance(p1,p2) {
  // haversine formula see http://www.movable-type.co.uk/scripts/latlong.html
  const EARTH_RADIUS = 3959; // in miles
  const dLat = radians(p2.lat) - radians(p1.lat);
  const dLon = radians(p2.lon) - radians(p1.lon);
  const a = Math.pow(Math.sin(dLat / 2),2)
    + Math.cos(radians(p2.lat))
    * Math.cos(radians(p1.lat))
    * Math.pow(Math.sin(dLon / 2), 2);
  const c = 2 * Math.atan2(Math.sqrt(a), Math.sqrt(1-a));
  return EARTH_RADIUS * c;
}
function radians(degrees) {
  return degrees * Math.PI / 180;
}

```

I can see that `distance` only uses `radians` and `radians` doesn't use anything inside its current context. So rather than pass the functions, I might as well move them

too. I can make a small step in this direction by moving them from their current context to nest them inside the nested `calculateDistance`.

```
function trackSummary(points) {
  const totalTime = calculateTime();
  const totalDistance = calculateDistance();
  const pace = totalTime / 60 / totalDistance ;
  return {
    time: totalTime,
    distance: totalDistance,
    pace: pace
  };

  function calculateDistance() {
    let result = 0;
    for (let i = 1; i < points.length; i++) {
      result += distance(points[i-1], points[i]);
    }
    return result;

    function distance(p1,p2) { ... }
    function radians(degrees) { ... }
  }
}
```

By doing this, I can use both static analysis and testing to tell me if there are any complications. In this case all is well, so I can copy them over to `top_calculateDistance`.

```
function top_calculateDistance(points) {
  let result = 0;
  for (let i = 1; i < points.length; i++) {
    result += distance(points[i-1], points[i]);
  }
  return result;

  function distance(p1,p2) { ... }
  function radians(degrees) { ... }
}
```

Again, the copy doesn't change how the program runs, but does give me an opportunity for more static analysis. Had I not spotted that `distance` calls `radians`, the linter would have caught it at this step.

Now that I have prepared the table, it's time for the major change—the body of the original `calculateDistance` will now call `top_calculateDistance`:


```
function trackSummary(points) {
  const totalTime = calculateTime();
  const totalDistance = calculateDistance();
  const pace = totalTime / 60 / totalDistance ;
  return {
    time: totalTime,
    distance: totalDistance,
    pace: pace
  };

  function calculateDistance() {
    return top_calculateDistance(points);
  }
}
```

This is the crucial time to run tests to fully test that the moved function has bedded down in its new home.

With that done, it's like unpacking the boxes after moving house. The first thing is to decide whether to keep the original function that's just delegating or not. In this case, there are few callers and, as usual with nested functions, they are highly localized. So I'm happy to get rid of it.

```
function trackSummary(points) {
  const totalTime = calculateTime();
  const totalDistance = top_calculateDistance(points);
  const pace = totalTime / 60 / totalDistance ;
  return {
    time: totalTime,
    distance: totalDistance,
    pace: pace
  };
};
```

Now is also a good time to think about what I want the name to be. Since the top-level function has the highest visibility, I'd like it to have the best name. `totalDistance` seems like a good choice. I can't use that immediately since it will be shadowed by the variable inside `trackSummary`—but I don't see any reason to keep that anyway, so I use *Inline Variable (123)* on it.

```
function trackSummary(points) {
  const totalTime = calculateTime();
  const pace = totalTime / 60 / totalDistance(points) ;
  return {
    time: totalTime,
    distance: totalDistance(points),
    pace: pace
  };
};
```

```
function totalDistance(points) {
  let result = 0;
  for (let i = 1; i < points.length; i++) {
    result += distance(points[i-1], points[i]);
  }
  return result;
}
```

If I'd had the need to keep the variable, I'd have renamed it to something like `totalDistanceCache` or `distance`.

Since the functions for `distance` and `radians` don't depend on anything inside `totalDistance`, I prefer to move them to top level too, putting all four functions at the top level.

```
function trackSummary(points) { ... }
function totalDistance(points) { ... }
function distance(p1,p2) { ... }
function radians(degrees) { ... }
```

Some people would prefer to keep `distance` and `radians` inside `totalDistance` in order to restrict their visibility. In some languages that may be a consideration, but with ES 2015, JavaScript has an excellent module mechanism that's the best tool for controlling function visibility. In general, I'm wary of nested functions—they too easily set up hidden data interrelationships that can get hard to follow.

Example: Moving between Classes

To illustrate this variety of Move Function, I'll start here:

class Account...

```
get bankCharge() {
  let result = 4.5;
  if (this._daysOverdrawn > 0) result += this.overdraftCharge;
  return result;
}

get overdraftCharge() {
  if (this.type.isPremium) {
    const baseCharge = 10;
    if (this.daysOverdrawn <= 7)
      return baseCharge;
    else
      return baseCharge + (this.daysOverdrawn - 7) * 0.85;
  }
  else
    return this.daysOverdrawn * 1.75;
}
```

Coming up are changes that lead to different types of account having different algorithms for determining the charge. Thus it seems natural to move `overdraftCharge` to the account type class.

The first step is to look at the features that the `overdraftCharge` method uses and consider whether it is worth moving a batch of methods together. In this case I need the `daysOverdrawn` method to remain on the account class, because that will vary with individual accounts.

Next, I copy the method body over to the account type and get it to fit.

class AccountType...

```
overdraftCharge(daysOverdrawn) {
  if (this.isPremium) {
    const baseCharge = 10;
    if (daysOverdrawn <= 7)
      return baseCharge;
    else
      return baseCharge + (daysOverdrawn - 7) * 0.85;
  }
  else
    return daysOverdrawn * 1.75;
}
```

In order to get the method to fit in its new location, I need to deal with two call targets that change their scope. `isPremium` is now a simple call on `this`. With `daysOverdrawn` I have to decide—do I pass the value or do I pass the account? For the moment, I just pass the simple value but I may well change this in the future if I require more than just the days overdrawn from the account—especially if what I want from the account varies with the account type.

Next, I replace the original method body with a delegating call.

class Account...

```
get bankCharge() {
  let result = 4.5;
  if (this._daysOverdrawn > 0) result += this.overdraftCharge;
  return result;
}

get overdraftCharge() {
  return this.type.overdraftCharge(this.daysOverdrawn);
}
```

Then comes the decision of whether to leave the delegation in place or to inline `overdraftCharge`. Inlining results in:

class Account...

```
get bankCharge() {
  let result = 4.5;
  if (this._daysOverdrawn > 0)
    result += this.type.overdraftCharge(this.daysOverdrawn);
  return result;
}
```

In the earlier steps, I passed `daysOverdrawn` as a parameter—but if there's a lot of data from the account to pass, I might prefer to pass the account itself.

class Account...

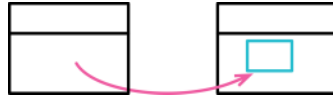
```
get bankCharge() {
  let result = 4.5;
  if (this.daysOverdrawn > 0) result += this.overdraftCharge;
  return result;
}

get overdraftCharge() {
  return this.type.overdraftCharge(this);
}
```

class AccountType...

```
overdraftCharge(account) {
  if (this.isPremium) {
    const baseCharge = 10;
    if (account.daysOverdrawn <= 7)
      return baseCharge;
    else
      return baseCharge + (account.daysOverdrawn - 7) * 0.85;
  }
  else
    return account.daysOverdrawn * 1.75;
}
```

Move Field



```
class Customer {  
  get plan() {return this._plan;}  
  get discountRate() {return this._discountRate;}  
}
```



```
class Customer {  
  get plan() {return this._plan;}  
  get discountRate() {return this.plan.discountRate;}  
}
```

Motivation

Programming involves writing a lot of code that implements behavior—but the strength of a program is really founded on its data structures. If I have a good set of data structures that match the problem, then my behavior code is simple and straightforward. But poor data structures lead to lots of code whose job is merely dealing with the poor data. And it's not just messier code that's harder to understand; it also means the data structures obscure what the program is doing.

So, data structures are important—but like most aspects of programming they are hard to get right. I do make an initial analysis to figure out the best data structures, and I've found that experience and techniques like domain-driven design have improved my ability to do that. But despite all my skill and experience, I still find that I frequently make mistakes in that initial design. In the process of programming, I learn more about the problem domain and my data structures. A design decision that is reasonable and correct one week can become wrong in another.

As soon as I realize that a data structure isn't right, it's vital to change it. If I leave my data structures with their blemishes, those blemishes will confuse my thinking and complicate my code far into the future.

I may seek to move data because I find I always need to pass a field from one record whenever I pass another record to a function. Pieces of data that are always passed to functions together are usually best put in a single record in order to

clarify their relationship. Change is also a factor; if a change in one record causes a field in another record to change too, that's a sign of a field in the wrong place. If I have to update the same field in multiple structures, that's a sign that it should move to another place where it only needs to be updated once.

I usually do Move Field in the context of a broader set of changes. Once I've moved a field, I find that many of the users of the field are better off accessing that data through the target object rather than the original source. I then change these with later refactorings. Similarly, I may find that I can't do Move Field at the moment due to the way the data is used. I need to refactor some usage patterns first, then do the move.

In my description so far, I'm saying "record," but all this is true of classes and objects too. A class is a record type with attached functions—and these need to be kept healthy just as much as any other data. The attached functions do make it easier to move data around, since the data is encapsulated behind accessor methods. I can move the data, change the accessors, and clients of the accessors will still work. So, this is a refactoring that's easier to do if you have classes, and my description below makes that assumption. If I'm using bare records that don't support encapsulation, I can still make a change like this, but it is more tricky.

Mechanics

- Ensure the source field is encapsulated.
- Test.
- Create a field (and accessors) in the target.
- Run static checks.
- Ensure there is a reference from the source object to the target object.

An existing field or method may give you the target. If not, see if you can easily create a method that will do so. Failing that, you may need to create a new field in the source object that can store the target. This may be a permanent change, but you can also do it temporarily until you have done enough refactoring in the broader context.

- Adjust accessors to use the target field.

If the target is shared between source objects, consider first updating the setter to modify both target and source fields, followed by *Introduce Assertion (302)* to detect inconsistent updates. Once you determine all is well, finish changing the accessors to use the target field.

- Test.

- Remove the source field.
- Test.

Example

I'm starting here with this customer and contract:

class Customer...

```

constructor(name, discountRate) {
  this._name = name;
  this._discountRate = discountRate;
  this._contract = new CustomerContract(dateToday());
}
get discountRate() {return this._discountRate;}
becomePreferred() {
  this._discountRate += 0.03;
  // other nice things
}
applyDiscount(amount) {
  return amount.subtract(amount.multiply(this._discountRate));
}

```

class CustomerContract...

```

constructor(startDate) {
  this._startDate = startDate;
}

```

I want to move the discount rate field from the customer to the customer contract.

The first thing I need to use is *Encapsulate Variable (132)* to encapsulate access to the discount rate field.

class Customer...

```

constructor(name, discountRate) {
  this._name = name;
  this._setDiscountRate(discountRate);
  this._contract = new CustomerContract(dateToday());
}
get discountRate() {return this._discountRate;}
_setDiscountRate(aNumber) {this._discountRate = aNumber;}
becomePreferred() {
  this._setDiscountRate(this.discountRate + 0.03);
  // other nice things
}
applyDiscount(amount) {
  return amount.subtract(amount.multiply(this.discountRate));
}

```

I use a method to update the discount rate, rather than a property setter, as I don't want to make a public setter for the discount rate.

I add a field and accessors to the customer contract.

class CustomerContract...

```
constructor(startDate, discountRate) {
  this._startDate = startDate;
  this._discountRate = discountRate;
}
get discountRate() {return this._discountRate;}
set discountRate(arg) {this._discountRate = arg;}
```

I now modify the accessors on customer to use the new field. When I did that, I got an error: "Cannot set property 'discountRate' of undefined". This was because `_setDiscountRate` was called before I created the contract object in the constructor. To fix that, I first reverted to the previous state, then used *Slide Statements (223)* to move the `_setDiscountRate` after creating the contract.

class Customer...

```
constructor(name, discountRate) {
  this._name = name;
  this._setDiscountRate(discountRate);
  this._contract = new CustomerContract(dateToday());
}
```

I tested that, then changed the accessors again to use the contract.

class Customer...

```
get discountRate() {return this._contract.discountRate;}
_setDiscountRate(aNumber) {this._contract.discountRate = aNumber;}
```

Since I'm using JavaScript, there is no declared source field, so I don't need to remove anything further.

Changing a Bare Record

This refactoring is generally easier with objects, since encapsulation provides a natural way to wrap data access in methods. If I have many functions accessing a bare record, then, while it's still a valuable refactoring, it is decidedly more tricky.

I can create accessor functions and modify all the reads and writes to use them. If the field that's being moved is immutable, I can update both the source and the target fields when I set its value and gradually migrate reads. Still, if possible, my first move would be to use *Encapsulate Record (162)* to turn the record into a class so I can make the change more easily.

Example: Moving to a Shared Object

Now, let's consider a different case. Here's an account with an interest rate:

```
class Account...
    constructor(number, type, interestRate) {
        this._number = number;
        this._type = type;
        this._interestRate = interestRate;
    }
    get interestRate() {return this._interestRate;}
```

```
class AccountType...
    constructor(nameString) {
        this._name = nameString;
    }
```

I want to change things so that an account's interest rate is determined from its account type.

The access to the interest rate is already nicely encapsulated, so I'll just create the field and an appropriate accessor on the account type.

```
class AccountType...
    constructor(nameString, interestRate) {
        this._name = nameString;
        this._interestRate = interestRate;
    }
    get interestRate() {return this._interestRate;}
```

But there is a potential problem when I update the accesses from account. Before this refactoring, each account had its own interest rate. Now, I want all accounts to share the interest rates of their account type. If all the accounts of the same type already have the same interest rate, then there's no change in observable behavior, so I'm fine with the refactoring. But if there's an account with a different interest rate, it's no longer a refactoring. If my account data is held in a database, I should check the database to ensure that all my accounts have the rate matching their type. I can also *Introduce Assertion* (302) in the account class.

```
class Account...
    constructor(number, type, interestRate) {
        this._number = number;
        this._type = type;
        assert(interestRate === this._type.interestRate);
        this._interestRate = interestRate;
    }
    get interestRate() {return this._interestRate;}
```

I might run the system for a while with this assertion in place to see if I get an error. Or, instead of adding an assertion, I might log the problem. Once I'm confident that I'm not introducing an observable change, I can change the access, removing the update from the account completely.

class Account...

```
    constructor(number, type) {  
        this._number = number;  
        this._type = type;  
    }  
    get interestRate() {return this._type.interestRate;}
```

Move Statements into Function

inverse of: *Move Statements to Callers* (217)



```
result.push('<p>title: ${person.photo.title}</p>');
result.concat(photoData(person.photo));

function photoData(aPhoto) {
  return [
    '<p>location: ${aPhoto.location}</p>',
    '<p>date: ${aPhoto.date.toDateString()}</p>',
  ];
}
```



```
result.concat(photoData(person.photo));

function photoData(aPhoto) {
  return [
    '<p>title: ${aPhoto.title}</p>',
    '<p>location: ${aPhoto.location}</p>',
    '<p>date: ${aPhoto.date.toDateString()}</p>',
  ];
}
```

Motivation

Removing duplication is one of the best rules of thumb of healthy code. If I see the same code executed every time I call a particular function, I look to combine that repeating code into the function itself. That way, any future modifications to the repeating code can be done in one place and used by all the callers. Should the code vary in the future, I can easily move it (or some of it) out again with *Move Statements to Callers* (217).

I move statements into a function when I can best understand these statements as part of the called function. If they don't make sense as part of the called function, but still should be called with it, I'll simply use *Extract Function (106)* on the statements and the called function. That's essentially the same process as I describe below, but without the inline and rename steps. It's not unusual to do that and then, after later reflection, carry out those final steps.

Mechanics

- If the repetitive code isn't adjacent to the call of the target function, use *Slide Statements (223)* to get it adjacent.
- If the target function is only called by the source function, just cut the code from the source, paste it into the target, test, and ignore the rest of these mechanics.
- If you have more callers, use *Extract Function (106)* on one of the call sites to extract both the call to the target function and the statements you wish to move into it. Give it a name that's transient, but easy to grep.
- Convert every other call to use the new function. Test after each conversion.
- When all the original calls use the new function, use *Inline Function (115)* to inline the original function completely into the new function, removing the original function.
- *Rename Function (124)* to change the name of the new function to the same name as the original function.

Or to a better name, if there is one.

Example

I'll start with this code to emit HTML for data about a photo:

```
function renderPerson(outStream, person) {
  const result = [];
  result.push(`<p>${person.name}</p>`);
  result.push(renderPhoto(person.photo));
  result.push(`<p>title: ${person.photo.title}</p>`);
  result.push(emitPhotoData(person.photo));
  return result.join("\n");
}
```

```
function photoDiv(p) {
  return [
    "<div>",
    '<p>title: ${p.title}</p>',
    emitPhotoData(p),
    "</div>",
  ].join("\n");
}

function emitPhotoData(aPhoto) {
  const result = [];
  result.push('<p>location: ${aPhoto.location}</p>');
  result.push('<p>date: ${aPhoto.date.toDateString()}</p>');
  return result.join("\n");
}
```

This code shows two calls to `emitPhotoData`, each preceded by a line of code that is semantically equivalent. I'd like to remove this duplication by moving the title printing into `emitPhotoData`. If I had just the one caller, I would just cut and paste the code, but the more callers I have, the more I'm inclined to use a safer procedure.

I begin by using *Extract Function (106)* on one of the callers. I'm extracting the statements I want to move into `emitPhotoData`, together with the call to `emitPhotoData` itself.

```
function photoDiv(p) {
  return [
    "<div>",
    zznew(p),
    "</div>",
  ].join("\n");
}

function zznew(p) {
  return [
    '<p>title: ${p.title}</p>',
    emitPhotoData(p),
  ].join("\n");
}
```

I can now look at the other callers of `emitPhotoData` and, one by one, replace the calls and the preceding statements with calls to the new function.

```
function renderPerson(outStream, person) {
  const result = [];
  result.push('<p>${person.name}</p>');
  result.push(renderPhoto(person.photo));
  result.push(zznew(person.photo));
  return result.join("\n");
}
```

Now that I've done all the callers, I use *Inline Function (115)* on `emitPhotoData`:

```
function zznew(p) {
  return [
    `

```

and finish with *Rename Function (124)*:

```
function renderPerson(outStream, person) {
  const result = [];
  result.push(`

```

I also make the parameter names fit my convention while I'm at it.

Move Statements to Callers

inverse of: *Move Statements into Function* (213)



```
emitPhotoData(outStream, person.photo);

function emitPhotoData(outStream, photo) {
  outStream.write(`<p>title: ${photo.title}</p>\n`);
  outStream.write(`<p>location: ${photo.location}</p>\n`);
}
```



```
emitPhotoData(outStream, person.photo);
outStream.write(`<p>location: ${person.photo.location}</p>\n`);

function emitPhotoData(outStream, photo) {
  outStream.write(`<p>title: ${photo.title}</p>\n`);
}
```

Motivation

Functions are the basic building block of the abstractions we build as programmers. And, as with any abstraction, we don't always get the boundaries right. As a code base changes its capabilities—as most useful software does—we often find our abstraction boundaries shift. For functions, that means that what might once have been a cohesive, atomic unit of behavior becomes a mix of two or more different things.

One trigger for this is when common behavior used in several places needs to vary in some of its calls. Now, we need to move the varying behavior out of the function to its callers. In this case, I'll use *Slide Statements* (223) to get the varying behavior to the beginning or end of the function and then *Move Statements to Callers*. Once the varying code is in the caller, I can change it when necessary.

Move Statements to Callers works well for small changes, but sometimes the boundaries between caller and callee need complete reworking. In that case, my best move is to use *Inline Function (115)* and then slide and extract new functions to form better boundaries.

Mechanics

- In simple circumstances, where you have only one or two callers and a simple function to call from, just cut the first line from the called function and paste (and perhaps fit) it into the callers. Test and you're done.
- Otherwise, apply *Extract Function (106)* to all the statements that you *don't* wish to move; give it a temporary but easily searchable name.

If the function is a method that is overridden by subclasses, do the extraction on all of them so that the remaining method is identical in all classes. Then remove the subclass methods.

- Use *Inline Function (115)* on the original function.
- Apply *Change Function Declaration (124)* on the extracted function to rename it to the original name.

Or to a better name, if you can think of one.

Example

Here's a simple case: a function with two callers.

```
function renderPerson(outStream, person) {
  outStream.write(`<p>${person.name}</p>\n`);
  renderPhoto(outStream, person.photo);
  emitPhotoData(outStream, person.photo);
}

function listRecentPhotos(outStream, photos) {
  photos
    .filter(p => p.date > recentDateCutoff())
    .forEach(p => {
      outStream.write("<div>\n");
      emitPhotoData(outStream, p);
      outStream.write("</div>\n");
    });
}

function emitPhotoData(outStream, photo) {
  outStream.write(`<p>title: ${photo.title}</p>\n`);
  outStream.write(`<p>date: ${photo.date.toString()}</p>\n`);
  outStream.write(`<p>location: ${photo.location}</p>\n`);
}
```


I need to modify the software so that `listRecentPhotos` renders the location information differently while `renderPerson` stays the same. To make this change easier, I'll use Move Statements to Callers on the final line.

Usually, when faced with something this simple, I'll just cut the last line from `renderPerson` and paste it below the two calls. But since I'm explaining what to do in more tricky cases, I'll go through the more elaborate but safer procedure.

My first step is to use *Extract Function (106)* on the code that will remain in `emitPhotoData`.

```
function renderPerson(outStream, person) {
  outStream.write(`<p>${person.name}</p>\n`);
  renderPhoto(outStream, person.photo);
  emitPhotoData(outStream, person.photo);
}

function listRecentPhotos(outStream, photos) {
  photos
    .filter(p => p.date > recentDateCutoff())
    .forEach(p => {
      outStream.write("<div>\n");
      emitPhotoData(outStream, p);
      outStream.write("</div>\n");
    });
}

function emitPhotoData(outStream, photo) {
  zztmp(outStream, photo);
  outStream.write(`<p>location: ${photo.location}</p>\n`);
}

function zztmp(outStream, photo) {
  outStream.write(`<p>title: ${photo.title}</p>\n`);
  outStream.write(`<p>date: ${photo.date.toDateString()}</p>\n`);
}
```

Usually, the name of the extracted function is only temporary, so I don't worry about coming up with anything meaningful. However, it is helpful to use something that's easy to grep. I can test at this point to ensure the code works over the function call boundary.

Now I use *Inline Function (115)*, one call at a time. I start with `renderPerson`.

```
function renderPerson(outStream, person) {
  outStream.write(`<p>${person.name}</p>\n`);
  renderPhoto(outStream, person.photo);
  zztmp(outStream, person.photo);
  outStream.write(`<p>location: ${person.photo.location}</p>\n`);
}
```

```

function listRecentPhotos(outStream, photos) {
  photos
    .filter(p => p.date > recentDateCutoff())
    .forEach(p => {
      outStream.write("<div>\n");
      emitPhotoData(outStream, p);
      outStream.write("</div>\n");
    });
}

function emitPhotoData(outStream, photo) {
  zztmp(outStream, photo);
  outStream.write("<p>location: ${photo.location}</p>\n");
}

function zztmp(outStream, photo) {
  outStream.write("<p>title: ${photo.title}</p>\n");
  outStream.write("<p>date: ${photo.date.toString()}</p>\n");
}

```

I test again to ensure this call is working properly, then move onto the next.

```

function renderPerson(outStream, person) {
  outStream.write("<p>${person.name}</p>\n");
  renderPhoto(outStream, person.photo);
  zztmp(outStream, person.photo);
  outStream.write("<p>location: ${person.photo.location}</p>\n");
}

function listRecentPhotos(outStream, photos) {
  photos
    .filter(p => p.date > recentDateCutoff())
    .forEach(p => {
      outStream.write("<div>\n");
      zztmp(outStream, p);
      outStream.write("<p>location: ${p.location}</p>\n");
      outStream.write("</div>\n");
    });
}

function emitPhotoData(outStream, photo) {
  zztmp(outStream, photo);
  outStream.write("<p>location: ${photo.location}</p>\n");
}

function zztmp(outStream, photo) {
  outStream.write("<p>title: ${photo.title}</p>\n");
  outStream.write("<p>date: ${photo.date.toString()}</p>\n");
}

```

Then I can delete the outer function, completing *Inline Function (115)*.

```
function renderPerson(outStream, person) {
  outStream.write(`

${person.name}</p>\n`);
  renderPhoto(outStream, person.photo);
  zztmp(outStream, person.photo);
  outStream.write(`

location: ${person.photo.location}</p>\n`);
}


```

```
function listRecentPhotos(outStream, photos) {
  photos
    .filter(p => p.date > recentDateCutoff())
    .forEach(p => {
      outStream.write("<div>\n");
      zztmp(outStream, p);
      outStream.write(`

location: ${p.location}</p>\n`);
      outStream.write("</div>\n");
    });
}


```

```
function emitPhotoData(outStream, photo) {
  zztmp(outStream, photo);
  outStream.write(`

location: ${photo.location}</p>\n`);
}


```

```
function zztmp(outStream, photo) {
  outStream.write(`

title: ${photo.title}</p>\n`);
  outStream.write(`

date: ${photo.date.toDateString()}</p>\n`);
}


```

I then rename zztmp back to the original name.

```
function renderPerson(outStream, person) {
  outStream.write(`

${person.name}</p>\n`);
  renderPhoto(outStream, person.photo);
  emitPhotoData(outStream, person.photo);
  outStream.write(`

location: ${person.photo.location}</p>\n`);
}


```

```
function listRecentPhotos(outStream, photos) {
  photos
    .filter(p => p.date > recentDateCutoff())
    .forEach(p => {
      outStream.write("<div>\n");
      emitPhotoData(outStream, p);
      outStream.write(`

location: ${p.location}</p>\n`);
      outStream.write("</div>\n");
    });
}


```

```
function emitPhotoData(outStream, photo) {
  outStream.write(`

title: ${photo.title}</p>\n`);
  outStream.write(`

date: ${photo.date.toDateString()}</p>\n`);
}


```

Replace Inline Code with Function Call



```
let appliesToMass = false;
for(const s of states) {
  if (s === "MA") appliesToMass = true;
}
```



```
appliesToMass = states.includes("MA");
```

Motivation

Functions allow me to package up bits of behavior. This is useful for understanding—a named function can explain the purpose of the code rather than its mechanics. It's also valuable to remove duplication: Instead of writing the same code twice, I just call the function. Then, should I need to change the function's implementation, I don't have to track down similar-looking code to update all the changes. (I may have to look at the callers, to see if they should all use the new code, but that's both less common and much easier.)

If I see inline code that's doing the same thing that I have in an existing function, I'll usually want to replace that inline code with a function call. The exception is if I consider the similarity to be coincidental—so that, if I change the function body, I don't expect the behavior in this inline code to change. A guide to this is the name of the function. A good name should make sense in place of inline code I have. If the name doesn't make sense, that may be because it's a poor name (in which case I use *Rename Function* (124) to fix it) or because the function's purpose is different to what I want in this case—so I shouldn't call it.

I find it particularly satisfying to do this with calls to library functions—that way, I don't even have to write the function body.

Mechanics

- Replace the inline code with a call to the existing function.
- Test.

Slide Statements

formerly: *Consolidate Duplicate Conditional Fragments*



```
const pricingPlan = retrievePricingPlan();
const order = retrieveOrder();
let charge;
const chargePerUnit = pricingPlan.unit;
```



```
const pricingPlan = retrievePricingPlan();
const chargePerUnit = pricingPlan.unit;
const order = retrieveOrder();
let charge;
```

Motivation

Code is easier to understand when things that are related to each other appear together. If several lines of code access the same data structure, it's best for them to be together rather than intermingled with code accessing other data structures. At its simplest, I use Slide Statements to keep such code together. A very common case of this is declaring and using variables. Some people like to declare all their variables at the top of a function. I prefer to declare the variable just before I first use it.

Usually, I move related code together as a preparatory step for another refactoring, often an *Extract Function* (106). Putting related code into a clearly separated function is a better separation than just moving a set of lines together, but I can't do the *Extract Function* (106) unless the code is together in the first place.

Mechanics

- Identify the target position to move the fragment to. Examine statements between source and target to see if there is interference for the candidate fragment. Abandon action if there is any interference.

A fragment cannot slide backwards earlier than any element it references is declared.

A fragment cannot slide forwards beyond any element that references it.

A fragment cannot slide over any statement that modifies an element it references.

A fragment that modifies an element cannot slide over any other element that references the modified element.

- Cut the fragment from the source and paste into the target position.
- Test.

If the test fails, try breaking down the slide into smaller steps. Either slide over less code or reduce the amount of code in the fragment you're moving.

Example

When sliding code fragments, there are two decisions involved: what slide I'd like to do and whether I can do it. The first decision is very context-specific. On the simplest level, I like to declare elements close to where I use them, so I'll often slide a declaration down to its usage. But almost always I slide some code because I want to do another refactoring—perhaps to get a clump of code together to *Extract Function* (106).

Once I have a sense of where I'd like to move some code, the next part is deciding if I can do it. This involves looking at the code I'm sliding and the code I'm sliding over: Do they interfere with each other in a way that would change the observable behavior of the program?

Consider the following fragment of code:

```
1 const pricingPlan = retrievePricingPlan();
2 const order = retrieveOrder();
3 const baseCharge = pricingPlan.base;
4 let charge;
5 const chargePerUnit = pricingPlan.unit;
6 const units = order.units;
7 let discount;
8 charge = baseCharge + units * chargePerUnit;
9 let discountableUnits = Math.max(units - pricingPlan.discountThreshold, 0);
10 discount = discountableUnits * pricingPlan.discountFactor;
11 if (order.isRepeat) discount += 20;
12 charge = charge - discount;
13 chargeOrder(charge);
```

The first seven lines are declarations, and it's relatively easy to move these. For example, I may want to move all the code dealing with discounts together, which would involve moving line 7 (`let discount`) to above line 10 (`discount = ...`). Since a declaration has no side effects and refers to no other variable, I can safely move this forwards as far as the first line that references `discount` itself. This is also a common move—if I want to use *Extract Function* (106) on the discount logic, I'll need to move the declaration down first.

I do similar analysis with any code that doesn't have side effects. So I can take line 2 (``const order = ...``) and move it down to above line 6 (``const units = ...``) without trouble.

In this case, I'm also helped by the fact that the code I'm moving over doesn't have side effects either. Indeed, I can freely rearrange code that lacks side effects to my heart's content, which is one of the reasons why wise programmers prefer to use side-effect-free code as much as possible.

There is a wrinkle here, however. How do I know that line 2 is side-effect-free? To be sure, I'd need to look inside `retrieveOrder()` to ensure there are no side effects there (and inside any functions it calls, and inside any functions its functions call, and so on). In practice, when working on my own code, I know that I generally follow the Command-Query Separation [mf-cqs] principle, so any function that returns a value is free of side effects. But I can only be confident of that because I know the code base; if I were working in an unknown code base, I'd have to be more cautious. But I do try to follow the Command-Query Separation in my own code because it's so valuable to know that code is free of side effects.

When sliding code that has a side effect, or sliding over code with side effects, I have to be much more careful. What I'm looking for is interference between the two code fragments. So, let's say I want to slide line 11 (``if (order.isRepeat) ...``) down to the end. I'm prevented from doing that by line 12 because it references the variable whose state I'm changing in line 11. Similarly, I can't take line 13 (``chargeOrder(charge)``) and move it up because line 12 modifies some state that line 13 references. However, I can slide line 8 (``charge = baseCharge + ...``) over lines 9–11 because there they don't modify any common state.

The most straightforward rule to follow is that I can't slide one fragment of code over another if any data that both fragments refer to is modified by either one. But that's not a comprehensive rule; I can happily slide either of the following two lines over the other:

```
a = a + 10;  
a = a + 5;
```

But judging whether a slide is safe means I have to really understand the operations involved and how they compose.

Since I need to worry so much about updating state, I look to remove as much of it as I can. So with this code, I'd be looking to apply *Split Variable (240)* on `charge` before I indulge in any sliding around of that code.

Here, the analysis is relatively simple because I'm mostly just modifying local variables. With more complex data structures, it's much harder to be sure when I get interference. So tests play an important role: Slide the fragment, run tests, see if things break. If my test coverage is good, I can feel happy with the refactoring. But if tests aren't reliable, I need to be more wary—or, more likely, to improve the tests for the code I'm working on.

The most important consequence of a test failure after a slide is to use smaller slides: Instead of sliding over ten lines, I'll just pick five, or slide up to what I reckon is a dangerous line. It may also mean that the slide isn't worth it, and I need to work on something else first.

Example: Sliding with Conditionals

I can also do slides with conditionals. This will either involve removing duplicate logic when I slide out of a conditional, or adding duplicate logic when I slide in.

Here's a case where I have the same statements in both legs of a conditional:

```
let result;
if (availableResources.length === 0) {
  result = createResource();
  allocatedResources.push(result);
} else {
  result = availableResources.pop();
  allocatedResources.push(result);
}
return result;
```

I can slide these out of the conditional, in which case they turn into a single statement outside of the conditional block.

```
let result;
if (availableResources.length === 0) {
  result = createResource();
} else {
  result = availableResources.pop();
}
allocatedResources.push(result);
return result;
```

In the reverse case, sliding a fragment into a conditional means repeating it in every leg of the conditional.

Further Reading

I've seen an almost identical refactoring under the name of Swap Statement [[wake-swap](#)]. Swap Statement moves adjacent fragments, but it only works with single-statement fragments. You can think of it as Slide Statements where both the sliding fragment and the slid-over fragment are single statements. This refactoring appeals to me; after all, I'm always going on about taking small steps—steps that may seem ridiculously small to those new to refactoring.

But I ended up writing this refactoring with larger fragments because that is what I do. I only move one statement at a time if I'm having difficulty with a larger slide, and I rarely run into problems with larger slides. With more messy code, however, smaller slides end up being easier.

Split Loop



```
let averageAge = 0;
let totalSalary = 0;
for (const p of people) {
  averageAge += p.age;
  totalSalary += p.salary;
}
averageAge = averageAge / people.length;
```



```
let totalSalary = 0;
for (const p of people) {
  totalSalary += p.salary;
}

let averageAge = 0;
for (const p of people) {
  averageAge += p.age;
}
averageAge = averageAge / people.length;
```

Motivation

You often see loops that are doing two different things at once just because they can do that with one pass through a loop. But if you're doing two different things in the same loop, then whenever you need to modify the loop you have

to understand both things. By splitting the loop, you ensure you only need to understand the behavior you need to modify.

Splitting a loop can also make it easier to use. A loop that calculates a single value can just return that value. Loops that do many things need to return structures or populate local variables. I frequently follow a sequence of Split Loop followed by *Extract Function* (106).

Many programmers are uncomfortable with this refactoring, as it forces you to execute the loop twice. My reminder, as usual, is to separate refactoring from optimization (*Refactoring and Performance* (64)). Once I have my code clear, I'll optimize it, and if the loop traversal is a bottleneck, it's easy to slam the loops back together. But the actual iteration through even a large list is rarely a bottleneck, and splitting the loops often enables other, more powerful, optimizations.

Mechanics

- Copy the loop.
- Identify and eliminate duplicate side effects.
- Test.

When done, consider *Extract Function* (106) on each loop.

Example

I'll start with a little bit of code that calculates the total salary and youngest age.

```
let youngest = people[0] ? people[0].age : Infinity;
let totalSalary = 0;
for (const p of people) {
  if (p.age < youngest) youngest = p.age;
  totalSalary += p.salary;
}

return `youngestAge: ${youngest}, totalSalary: ${totalSalary}`;
```

It's a very simple loop, but it's doing two different calculations. To split them, I begin with just copying the loop.

```
let youngest = people[0] ? people[0].age : Infinity;
let totalSalary = 0;
for (const p of people) {
  if (p.age < youngest) youngest = p.age;
  totalSalary += p.salary;
}
```

```

for (const p of people) {
  if (p.age < youngest) youngest = p.age;
  totalSalary += p.salary;
}

return `youngestAge: ${youngest}, totalSalary: ${totalSalary}`;

```

With the loop copied, I need to remove the duplication that would otherwise produce wrong results. If something in the loop has no side effects, I can leave it there for now, but it's not the case with this example.

```

let youngest = people[0] ? people[0].age : Infinity;
let totalSalary = 0;
for (const p of people) {
  if (p.age < youngest) youngest = p.age;
  totalSalary += p.salary;
}

for (const p of people) {
  if (p.age < youngest) youngest = p.age;
  totalSalary += p.salary;
}

return `youngestAge: ${youngest}, totalSalary: ${totalSalary}`;

```

Officially, that's the end of the Split Loop refactoring. But the point of Split Loop isn't what it does on its own but what it sets up for the next move—and I'm usually looking to extract the loops into their own functions. I'll use *Slide Statements* (223) to reorganize the code a bit first.

```

let totalSalary = 0;
for (const p of people) {
  totalSalary += p.salary;
}

let youngest = people[0] ? people[0].age : Infinity;
for (const p of people) {
  if (p.age < youngest) youngest = p.age;
}

return `youngestAge: ${youngest}, totalSalary: ${totalSalary}`;

```

Then I do a couple of *Extract Function* (106).

```
return `youngestAge: ${youngestAge()}, totalSalary: ${totalSalary()}`;

function totalSalary() {
  let totalSalary = 0;
  for (const p of people) {
    totalSalary += p.salary;
  }
  return totalSalary;
}

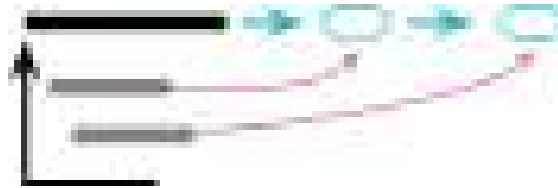
function youngestAge() {
  let youngest = people[0] ? people[0].age : Infinity;
  for (const p of people) {
    if (p.age < youngest) youngest = p.age;
  }
  return youngest;
}
```

I can rarely resist *Replace Loop with Pipeline* (231) for the total salary, and there's an obvious *Substitute Algorithm* (195) for the youngest age.

```
return `youngestAge: ${youngestAge()}, totalSalary: ${totalSalary()}`;

function totalSalary() {
  return people.reduce((total,p) => total + p.salary, 0);
}
function youngestAge() {
  return Math.min(...people.map(p => p.age));
}
```

Replace Loop with Pipeline



```
const names = [];  
for (const i of input) {  
  if (i.job === "programmer")  
    names.push(i.name);  
}
```



```
const names = input  
  .filter(i => i.job === "programmer")  
  .map(i => i.name)  
;
```

Motivation

Like most programmers, I was taught to use loops to iterate over a collection of objects. Increasingly, however, language environments provide a better construct: the collection pipeline. Collection Pipelines [mf-cp] allow me to describe my processing as a series of operations, each consuming and emitting a collection. The most common of these operations are *map*, which uses a function to transform each element of the input collection, and *filter* which uses a function to select a subset of the input collection for later steps in the pipeline. I find logic much easier to follow if it is expressed as a pipeline—I can then read from top to bottom to see how objects flow through the pipeline.

Mechanics

- Create a new variable for the loop's collection.

This may be a simple copy of an existing variable.

- Starting at the top, take each bit of behavior in the loop and replace it with a collection pipeline operation in the derivation of the loop collection variable. Test after each change.
- Once all behavior is removed from the loop, remove it.

If it assigns to an accumulator, assign the pipeline result to the accumulator.

Example

I'll begin with some data: a CSV file of data about our offices.

```
office, country, telephone
Chicago, USA, +1 312 373 1000
Beijing, China, +86 4008 900 505
Bangalore, India, +91 80 4064 9570
Porto Alegre, Brazil, +55 51 3079 3550
Chennai, India, +91 44 660 44766
```

... (more data follows)

The following function picks out the offices in India and returns their cities and telephone numbers:

```
function acquireData(input) {
  const lines = input.split("\n");
  let firstLine = true;
  const result = [];
  for (const line of lines) {
    if (firstLine) {
      firstLine = false;
      continue;
    }
    if (line.trim() === "") continue;
    const record = line.split(",");
    if (record[1].trim() === "India") {
      result.push({city: record[0].trim(), phone: record[2].trim()});
    }
  }
  return result;
}
```

I want to replace that loop with a collection pipeline.

My first step is to create a separate variable for the loop to work over.

```
function acquireData(input) {
  const lines = input.split("\n");
  let firstLine = true;
  const result = [];
  const loopItems = lines
  for (const line of loopItems) {
    if (firstLine) {
      firstLine = false;
      continue;
    }
    if (line.trim() === "") continue;
    const record = line.split(",");
    if (record[1].trim() === "India") {
      result.push({city: record[0].trim(), phone: record[2].trim()});
    }
  }
  return result;
}
```

The first part of the loop is all about skipping the first line of the CSV file. This calls for a slice, so I remove that first section of the loop and add a slice operation to the formation of the loop variable.

```
function acquireData(input) {
  const lines = input.split("\n");
  let firstLine = true;
  const result = [];
  const loopItems = lines
    .slice(1);
  for (const line of loopItems) {
    if (firstLine) {
      firstLine = false;
      continue;
    }
    if (line.trim() === "") continue;
    const record = line.split(",");
    if (record[1].trim() === "India") {
      result.push({city: record[0].trim(), phone: record[2].trim()});
    }
  }
  return result;
}
```

As a bonus, this lets me delete `firstLine`—and I particularly enjoy deleting control variables.

The next bit of behavior removes any blank lines. I can replace this with a filter operation.

```
function acquireData(input) {
  const lines = input.split("\n");
  const result = [];
  const loopItems = lines
    .slice(1)
    .filter(line => line.trim() !== "");
  ;
  for (const line of loopItems) {
    if (line.trim() === "") continue;
    const record = line.split(",");
    if (record[1].trim() === "India") {
      result.push({city: record[0].trim(), phone: record[2].trim()});
    }
  }
  return result;
}
```

When writing a pipeline, I find it best to put the terminal semicolon on its own line.

I use the map operation to turn lines into an array of strings—misleadingly called record in the original function, but it's safer to keep the name for now and rename later.

```
function acquireData(input) {
  const lines = input.split("\n");
  const result = [];
  const loopItems = lines
    .slice(1)
    .filter(line => line.trim() !== "")
    .map(line => line.split(","))
    ;
  for (const line of loopItems) {
    const record = line; split(",");
    if (record[1].trim() === "India") {
      result.push({city: record[0].trim(), phone: record[2].trim()});
    }
  }
  return result;
}
```

Filter again to just get the India records:


```
function acquireData(input) {
  const lines = input.split("\n");
  const result = [];
  const loopItems = lines
    .slice(1)
    .filter(line => line.trim() !== "")
    .map(line => line.split(","))
    .filter(record => record[1].trim() === "India")
    ;
  for (const line of loopItems) {
    const record = line;
    if (record[1].trim() === "India") {
      result.push({city: record[0].trim(), phone: record[2].trim()});
    }
  }
  return result;
}
```

Map to the output record form:

```
function acquireData(input) {
  const lines = input.split("\n");
  const result = [];
  const loopItems = lines
    .slice(1)
    .filter(line => line.trim() !== "")
    .map(line => line.split(","))
    .filter(record => record[1].trim() === "India")
    .map(record => ({city: record[0].trim(), phone: record[2].trim()}))
    ;
  for (const line of loopItems) {
    const record = line;
    result.push(line);
  }
  return result;
}
```

Now, all the loop does is assign values to the accumulator. So I can remove it and assign the result of the pipeline to the accumulator:

```
function acquireData(input) {
  const lines = input.split("\n");
  const result = lines
    .slice(1)
    .filter(line => line.trim() !== "")
    .map(line => line.split(","))
    .filter(record => record[1].trim() === "India")
    .map(record => ({city: record[0].trim(), phone: record[2].trim()}))
  ;
for (const line of loopItems){
  const record = line;
  result.push(line);
}
  return result;
}
```

That's the core of the refactoring. But I do have some cleanup I'd like to do. I inlined `result`, renamed some lambda variables, and made the layout read more like a table.

```
function acquireData(input) {
  const lines = input.split("\n");
  return lines
    .slice (1)
    .filter (line  => line.trim() !== "")
    .map    (line  => line.split(","))
    .filter (fields => fields[1].trim() === "India")
    .map    (fields => ({city: fields[0].trim(), phone: fields[2].trim()}))
  ;
}
```

I thought about inlining `lines` too, but felt that its presence explains what's happening.

Further Reading

For more examples on turning loops into pipelines, see my essay "Refactoring with Loops and Collection Pipelines" [[mf-ref-pipe](#)].

Remove Dead Code



```
if(false) {  
    doSomethingThatUsedToMatter();  
}
```



Motivation

When we put code into production, even on people's devices, we aren't charged by weight. A few unused lines of code don't slow down our systems nor take up significant memory; indeed, decent compilers will instinctively remove them. But unused code is still a significant burden when trying to understand how the software works. It doesn't carry any warning signs telling programmers that they can ignore this function as it's never called any more, so they still have to spend time understanding what it's doing and why changing it doesn't seem to alter the output as they expected.

Once code isn't used any more, we should delete it. I don't worry that I may need it sometime in the future; should that happen, I have my version control system so I can always dig it out again. If it's something I really think I may need one day, I might put a comment into the code that mentions the lost code and which revision it was removed in—but, honestly, I can't remember the last time I did that, or regretted that I hadn't done it.

Commenting out dead code was once a common habit. This was useful in the days before version control systems were widely used, or when they were inconvenient. Now, when I can put even the smallest code base under version control, that's no longer needed.

Mechanics

- If the dead code can be referenced from outside, e.g., when it's a full function, do a search to check for callers.
- Remove the dead code.
- Test.

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Chapter 9

Organizing Data

Data structures play an important role in our programs, so it's no great shock that I have a clutch of refactorings that focus on them. A value that's used for different purposes is a breeding ground for confusion and bugs—so, when I see one, I use *Split Variable* (240) to separate the usages. As with any program element, getting a variable's name right is tricky and important, so *Rename Variable* (137) is often my friend. But sometimes the best thing I can do with a variable is to get rid of it completely—with *Replace Derived Variable with Query* (248).

I often find problems in a code base due to a confusion between references and values, so I use *Change Reference to Value* (252) and *Change Value to Reference* (256) to change between these styles.

Split Variable

formerly: *Remove Assignments to Parameters*

formerly: *Split Temp*



```
let temp = 2 * (height + width);  
console.log(temp);  
temp = height * width;  
console.log(temp);
```



```
const perimeter = 2 * (height + width);  
console.log(perimeter);  
const area = height * width;  
console.log(area);
```

Motivation

Variables have various uses. Some of these uses naturally lead to the variable being assigned to several times. Loop variables change for each run of a loop (such as the `i` in `for (let i=0; i<10; i++)`). Collecting variables store a value that is built up during the method.

Many other variables are used to hold the result of a long-winded bit of code for easy reference later. These kinds of variables should be set only once. If they are set more than once, it is a sign that they have more than one responsibility within the method. Any variable with more than one responsibility should be replaced with multiple variables, one for each responsibility. Using a variable for two different things is very confusing for the reader.

Mechanics

- Change the name of the variable at its declaration and first assignment.

If the later assignments are of the form `i = i + something`, that is a collecting variable, so don't split it. A collecting variable is often used for calculating sums, string concatenation, writing to a stream, or adding to a collection.

- If possible, declare the new variable as immutable.
- Change all references of the variable up to its second assignment.
- Test.
- Repeat in stages, at each stage renaming the variable at the declaration and changing references until the next assignment, until you reach the final assignment.

Example

For this example, I compute the distance traveled by a haggis. From a standing start, a haggis experiences an initial force. After a delay, a secondary force kicks in to further accelerate the haggis. Using the common laws of motion, I can compute the distance traveled as follows:

```
function distanceTravelled (scenario, time) {  
  let result;  
  let acc = scenario.primaryForce / scenario.mass;  
  let primaryTime = Math.min(time, scenario.delay);  
  result = 0.5 * acc * primaryTime * primaryTime;  
  let secondaryTime = time - scenario.delay;  
  if (secondaryTime > 0) {  
    let primaryVelocity = acc * scenario.delay;  
    acc = (scenario.primaryForce + scenario.secondaryForce) / scenario.mass;  
    result += primaryVelocity * secondaryTime + 0.5 * acc * secondaryTime * secondaryTime;  
  }  
  return result;  
}
```

A nice awkward little function. The interesting thing for our example is the way the variable `acc` is set twice. It has two responsibilities: one to hold the initial acceleration from the first force and another later to hold the acceleration from both forces. I want to split this variable.

When trying to understand how a variable is used, it's handy if my editor can highlight all occurrences of a symbol within a function or file. Most modern editors can do this pretty easily.

I start at the beginning by changing the name of the variable and declaring the new name as `const`. Then, I change all references to the variable from that point up to the next assignment. At the next assignment, I declare it:

```
function distanceTravelled (scenario, time) {
  let result;
  const primaryAcceleration = scenario.primaryForce / scenario.mass;
  let primaryTime = Math.min(time, scenario.delay);
  result = 0.5 * primaryAcceleration * primaryTime * primaryTime;
  let secondaryTime = time - scenario.delay;
  if (secondaryTime > 0) {
    let primaryVelocity = primaryAcceleration * scenario.delay;
    let acc = (scenario.primaryForce + scenario.secondaryForce) / scenario.mass;
    result += primaryVelocity * secondaryTime + 0.5 * acc * secondaryTime * secondaryTime;
  }
  return result;
}
```

I choose the new name to represent only the first use of the variable. I make it `const` to ensure it is only assigned once. I can then declare the original variable at its second assignment. Now I can compile and test, and all should work.

I continue on the second assignment of the variable. This removes the original variable name completely, replacing it with a new variable named for the second use.

```
function distanceTravelled (scenario, time) {
  let result;
  const primaryAcceleration = scenario.primaryForce / scenario.mass;
  let primaryTime = Math.min(time, scenario.delay);
  result = 0.5 * primaryAcceleration * primaryTime * primaryTime;
  let secondaryTime = time - scenario.delay;
  if (secondaryTime > 0) {
    let primaryVelocity = primaryAcceleration * scenario.delay;
    const secondaryAcceleration = (scenario.primaryForce + scenario.secondaryForce) / scenario.mass;
    result += primaryVelocity * secondaryTime +
      0.5 * secondaryAcceleration * secondaryTime * secondaryTime;
  }
  return result;
}
```

I'm sure you can think of a lot more refactoring to be done here. Enjoy it. (I'm sure it's better than eating the haggis—do you know what they put in those things?)

Example: Assigning to an Input Parameter

Another case of splitting a variable is where the variable is declared as an input parameter. Consider something like

```
function discount (inputValue, quantity) {
  if (inputValue > 50) inputValue = inputValue - 2;
  if (quantity > 100) inputValue = inputValue - 1;
  return inputValue;
}
```


Here `inputValue` is used both to supply an input to the function and to hold the result for the caller. (Since JavaScript has call-by-value parameters, any modification of `inputValue` isn't seen by the caller.)

In this situation, I would split that variable.

```
function discount (originalInputValue, quantity) {  
  let inputValue = originalInputValue;  
  if (inputValue > 50) inputValue = inputValue - 2;  
  if (quantity > 100) inputValue = inputValue - 1;  
  return inputValue;  
}
```

I then perform *Rename Variable (137)* twice to get better names.

```
function discount (inputValue, quantity) {  
  let result = inputValue;  
  if (inputValue > 50) result = result - 2;  
  if (quantity > 100) result = result - 1;  
  return result;  
}
```

You'll notice that I changed the second line to use `inputValue` as its data source. Although the two are the same, I think that line is really about applying the modification to the result value based on the original input value, not the (coincidentally same) value of the result accumulator.

Rename Field



```
class Organization {  
    get name() {...}  
}
```



```
class Organization {  
    get title() {...}  
}
```

Motivation

Names are important, and field names in record structures can be especially important when those record structures are widely used across a program. Data structures play a particularly important role in understanding. Many years ago Fred Brooks said, “Show me your flowcharts and conceal your tables, and I shall continue to be mystified. Show me your tables, and I won’t usually need your flowcharts; they’ll be obvious.” While I don’t see many people drawing flowcharts these days, the adage remains valid. Data structures are the key to understanding what’s going on.

Since these data structures are so important, it’s essential to keep them clear. Like anything else, my understanding of data improves the more I work on the software, so it’s vital that this improved understanding is embedded into the program.

You may want to rename a field in a record structure, but the idea also applies to classes. Getter and setter methods form an effective field for users of the class. Renaming them is just as important as with bare record structures.

Mechanics

- If the record has limited scope, rename all accesses to the field and test; no need to do the rest of the mechanics.

- If the record isn't already encapsulated, apply *Encapsulate Record (162)*.
- Rename the private field inside the object, adjust internal methods to fit.
- Test.
- If the constructor uses the name, apply *Change Function Declaration (124)* to rename it.
- Apply *Rename Function (124)* to the accessors.

Example: Renaming a Field

I'll start with a constant.

```
const organization = {name: "Acme Gooseberries", country: "GB"};
```

I want to change “name” to “title”. The object is widely used in the code base, and there are updates to the title in the code. So my first move is to apply *Encapsulate Record (162)*.

```
class Organization {
  constructor(data) {
    this._name = data.name;
    this._country = data.country;
  }
  get name() {return this._name;}
  set name(aString) {this._name = aString;}
  get country() {return this._country;}
  set country(aCountryCode) {this._country = aCountryCode;}
}
```

```
const organization = new Organization({name: "Acme Gooseberries", country: "GB"});
```

Now that I've encapsulated the record structure into the class, there are four places I need to look at for renaming: the getting function, the setting function, the constructor, and the internal data structure. While that may sound like I've increased my workload, it actually makes my work easier since I can now change these independently instead of all at once, taking smaller steps. Smaller steps mean fewer things to go wrong in each step—therefore, less work. It wouldn't be less work if I never made mistakes—but not making mistakes is a fantasy I gave up on a long time ago.

Since I've copied the input data structure into the internal data structure, I need to separate them so I can work on them independently. I can do this by defining a separate field and adjusting the constructor and accessors to use it.

class Organization...

```
class Organization {
  constructor(data) {
    this._title = data.name;
    this._country = data.country;
  }
  get name() {return this._title;}
  set name(aString) {this._title = aString;}
  get country() {return this._country;}
  set country(aCountryCode) {this._country = aCountryCode;}
}
```

Next, I add support for using “title” in the constructor.

class Organization...

```
class Organization {
  constructor(data) {
    this._title = (data.title !== undefined) ? data.title : data.name;
    this._country = data.country;
  }
  get name() {return this._title;}
  set name(aString) {this._title = aString;}
  get country() {return this._country;}
  set country(aCountryCode) {this._country = aCountryCode;}
}
```

Now, callers of my constructor can use either name or title (with title taking precedence). I can now go through all constructor callers and change them one-by-one to use the new name.

```
const organization = new Organization({title: "Acme Gooseberries", country: "GB"});
```

Once I’ve done all of them, I can remove the support for the name.

class Organization...

```
class Organization {
  constructor(data) {
    this._title = data.title;
    this._country = data.country;
  }
  get name() {return this._title;}
  set name(aString) {this._title = aString;}
  get country() {return this._country;}
  set country(aCountryCode) {this._country = aCountryCode;}
}
```

Now that the constructor and data use the new name, I can change the accessors, which is as simple as applying *Rename Function (124)* to each one.

class Organization...

```
class Organization {
  constructor(data) {
    this._title = data.title;
    this._country = data.country;
  }
  get title() {return this._title;}
  set title(aString) {this._title = aString;}
  get country() {return this._country;}
  set country(aCountryCode) {this._country = aCountryCode;}
}
```

I've shown this process in its most heavyweight form needed for a widely used data structure. If it's being used only locally, as in a single function, I can probably just rename the various properties in one go without doing encapsulation. It's a matter of judgment when to apply to the full mechanics here—but, as usual with refactoring, if my tests break, that's a sign I need to use the more gradual procedure.

Some languages allow me to make a data structure immutable. In this case, rather than encapsulating it, I can copy the value to the new name, gradually change the users, then remove the old name. Duplicating data is a recipe for disaster with mutable data structures; removing such disasters is why immutable data is so popular.

Replace Derived Variable with Query



```
get discountedTotal() {return this._discountedTotal;}
set discount(aNumber) {
  const old = this._discount;
  this._discount = aNumber;
  this._discountedTotal += old - aNumber;
}
```



```
get discountedTotal() {return this._baseTotal - this._discount;}
set discount(aNumber) {this._discount = aNumber;}
```

Motivation

One of the biggest sources of problems in software is mutable data. Data changes can often couple together parts of code in awkward ways, with changes in one part leading to knock-on effects that are hard to spot. In many situations it's not realistic to entirely remove mutable data—but I do advocate minimizing the scope of mutable data at much as possible.

One way I can make a big impact is by removing any variables that I could just as easily calculate. A calculation often makes it clearer what the meaning of the data is, and it is protected from being corrupted when you fail to update the variable as the source data changes.

A reasonable exception to this is when the source data for the calculation is immutable and we can force the result to being immutable too. Transformation operations that create new data structures are thus reasonable to keep even if they could be replaced with calculations. Indeed, there is a duality here between objects that wrap a data structure with a series of calculated properties and functions that transform one data structure into another. The object route is clearly better when the source data changes and you would have to manage the lifetime of the derived data structures. But if the source data is immutable, or the derived data is very transient, then both approaches are effective.

Mechanics

- Identify all points of update for the variable. If necessary, use *Split Variable (240)* to separate each point of update.
- Create a function that calculates the value of the variable.
- Use *Introduce Assertion (302)* to assert that the variable and the calculation give the same result whenever the variable is used.

If necessary, use *Encapsulate Variable (132)* to provide a home for the assertion.

- Test.
- Replace any reader of the variable with a call to the new function.
- Test.
- Apply *Remove Dead Code (237)* to the declaration and updates to the variable.

Example

Here's a small but perfectly formed example of ugliness:

```
class ProductionPlan...
  get production() {return this._production;}
  applyAdjustment(anAdjustment) {
    this._adjustments.push(anAdjustment);
    this._production += anAdjustment.amount;
  }
```

Ugliness is in the eye of beholder; here, I see ugliness in duplication—not the common duplication of code but duplication of data. When I apply an adjustment, I'm not just storing that adjustment but also using it to modify an accumulator. I can just calculate that value, without having to update it.

But I'm a cautious fellow. It is my hypothesis is that I can just calculate it—I can test that hypothesis by using *Introduce Assertion (302)*:

```
class ProductionPlan...
  get production() {
    assert(this._production === this.calculatedProduction);
    return this._production;
  }

  get calculatedProduction() {
    return this._adjustments
      .reduce((sum, a) => sum + a.amount, 0);
  }
```

With the assertion in place, I run my tests. If the assertion doesn't fail, I can replace returning the field with returning the calculation:

class ProductionPlan...

```
get production() {
  assert(this._production === this.calculatedProduction);
  return this.calculatedProduction;
}
```

Then *Inline Function (115)*:

class ProductionPlan...

```
get production() {
  return this._adjustments
    .reduce((sum, a) => sum + a.amount, 0);
}
```

I clean up any references to the old variable with *Remove Dead Code (237)*:

class ProductionPlan...

```
applyAdjustment(anAdjustment) {
  this._adjustments.push(anAdjustment);
  this._production += anAdjustment.amount;
}
```

Example: More Than One Source

The above example is nice and easy because there's clearly a single source for the value of production. But sometimes, more than one element can combine in the accumulator.

class ProductionPlan...

```
constructor (production) {
  this._production = production;
  this._adjustments = [];
}
get production() {return this._production;}
applyAdjustment(anAdjustment) {
  this._adjustments.push(anAdjustment);
  this._production += anAdjustment.amount;
}
```

If I do the same *Introduce Assertion (302)* that I did above, it will now fail for any case where the initial value of the production isn't zero.

But I can still replace the derived data. The only difference is that I must first apply *Split Variable (240)*.


```
constructor (production) {  
  this._initialProduction = production;  
  this._productionAccumulator = 0;  
  this._adjustments = [];  
}  
get production() {  
  return this._initialProduction + this._productionAccumulator;  
}
```

Now I can *Introduce Assertion* (302):

class ProductionPlan...

```
get production() {  
  assert(this._productionAccumulator === this.calculatedProductionAccumulator);  
  return this._initialProduction + this._productionAccumulator;  
}  
  
get calculatedProductionAccumulator() {  
  return this._adjustments  
    .reduce((sum, a) => sum + a.amount, 0);  
}
```

and continue pretty much as before. I'd be inclined, however, to leave `totalProductionAdjustments` as its own property, without inlining it.

Change Reference to Value

inverse of: *Change Value to Reference* (256)



```
class Product {  
    applyDiscount(arg) {this._price.amount -= arg;}
```



```
class Product {  
    applyDiscount(arg) {  
        this._price = new Money(this._price.amount - arg, this._price.currency);  
    }  
}
```

Motivation

When I nest an object, or data structure, within another I can treat the inner object as a reference or as a value. The difference is most obviously visible in how I handle updates of the inner object's properties. If I treat it as a reference, I'll update the inner object's property keeping the same inner object. If I treat it as a value, I will replace the entire inner object with a new one that has the desired property.

If I treat a field as a value, I can change the class of the inner object to make it a Value Object [mf-vo]. Value objects are generally easier to reason about, particularly because they are immutable. In general, immutable data structures are easier to deal with. I can pass an immutable data value out to other parts of the program and not worry that it might change without the enclosing object being aware of the change. I can replicate values around my program and not worry about maintaining memory links. Value objects are especially useful in distributed and concurrent systems.

This also suggests when I shouldn't do this refactoring. If I want to share an object between several objects so that any change to the shared object is visible to all its collaborators, then I need the shared object to be a reference.

Mechanics

- Check that the candidate class is immutable or can become immutable.
- For each setter, apply *Remove Setting Method (331)*.
- Provide a value-based equality method that uses the fields of the value object.

Most language environments provide an overridable equality function for this purpose. Usually you must override a hashcode generator method as well.

Example

Imagine we have a person object that holds onto a crude telephone number.

class Person...

```
constructor() {
  this._telephoneNumber = new TelephoneNumber();
}

get officeAreaCode() {return this._telephoneNumber.areaCode;}
set officeAreaCode(arg) {this._telephoneNumber.areaCode = arg;}
get officeNumber() {return this._telephoneNumber.number;}
set officeNumber(arg) {this._telephoneNumber.number = arg;}
```

class TelephoneNumber...

```
get areaCode() {return this._areaCode;}
set areaCode(arg) {this._areaCode = arg;}

get number() {return this._number;}
set number(arg) {this._number = arg;}
```

This situation is the result of an *Extract Class (182)* where the old parent still holds update methods for the new object. This is a good time to apply Change Reference to Value since there is only one reference to the new class.

The first thing I need to do is to make the telephone number immutable. I do this by applying *Remove Setting Method (331)* to the fields. The first step of *Remove Setting Method (331)* is to use *Change Function Declaration (124)* to add the two fields to the constructor and enhance the constructor to call the setters.

class TelephoneNumber...

```
constructor(areaCode, number) {
  this._areaCode = areaCode;
  this._number = number;
}
```

Now I look at the callers of the setters. For each one, I need to change it to a reassignment. I start with the area code.

class Person...

```
get officeAreaCode() {return this._telephoneNumber.areaCode;}
set officeAreaCode(arg) {
  this._telephoneNumber = new TelephoneNumber(arg, this.officeNumber);
}
get officeNumber() {return this._telephoneNumber.number;}
set officeNumber(arg) {this._telephoneNumber.number = arg;}
```

I then repeat that step with the remaining field.

class Person...

```
get officeAreaCode() {return this._telephoneNumber.areaCode;}
set officeAreaCode(arg) {
  this._telephoneNumber = new TelephoneNumber(arg, this.officeNumber);
}
get officeNumber() {return this._telephoneNumber.number;}
set officeNumber(arg) {
  this._telephoneNumber = new TelephoneNumber(this.officeAreaCode, arg);
}
```

Now the telephone number is immutable, it is ready to become a true value. The citizenship test for a value object is that it uses value-based equality. This is an area where JavaScript falls down, as there is nothing in the language and core libraries that understands replacing a reference-based equality with a value-based one. The best I can do is to create my own equals method.

class TelephoneNumber...

```
equals(other) {
  if (!(other instanceof TelephoneNumber)) return false;
  return this.areaCode === other.areaCode &&
    this.number === other.number;
}
```

It's also important to test it with something like

```
it('telephone equals', function() {
  assert(
    new TelephoneNumber("312", "555-0142")
      .equals(new TelephoneNumber("312", "555-0142")));
});
```

The unusual formatting I use here should make it obvious that they are the same constructor call.

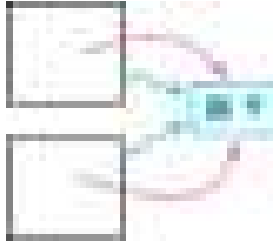
The vital thing I do in the test is create two independent objects and test that they match as equal.

In most object-oriented languages, there is a built-in equality test that is supposed to be overridden for value-based equality. In Ruby, I can override the `==` operator; in Java, I override the `Object.equals()` method. And whenever I override an equality method, I usually need to override a hashcode generating method too (e.g., `Object.hashCode()` in Java) to ensure collections that use hashing work properly with my new value.

If the telephone number is used by more than one client, the procedure is still the same. As I apply *Remove Setting Method (331)*, I'll be modifying several clients instead of just one. Tests for non-equal telephone numbers, as well as comparisons to non-telephone-numbers and null values, are also worthwhile.

Change Value to Reference

inverse of: *Change Reference to Value* (252)



```
let customer = new Customer(customerData);
```



```
let customer = customerRepository.get(customerData.id);
```

Motivation

A data structure may have several records linked to the same logical data structure. I might read in a list of orders, some of which are for the same customer. When I have sharing like this, I can represent it by treating the customer either as a value or as a reference. With a value, the customer data is copied into each order; with a reference, there is only one data structure that multiple orders link to.

If the customer never needs to be updated, then both approaches are reasonable. It is, perhaps, a bit confusing to have multiple copies of the same data, but it's common enough to not be a problem. In some cases, there may be issues with memory due to multiple copies—but, like any performance issue, that's relatively rare.

The biggest difficulty in having physical copies of the same logical data occurs when I need to update the shared data. I then have to find all the copies and update them all. If I miss one, I'll get a troubling inconsistency in my data. In this case, it's often worthwhile to change the copied data into a single reference. That way, any change is visible to all the customer's orders.

Changing a value to a reference results in only one object being present for an entity, and it usually means I need some kind of repository where I can access these objects. I then only create the object for an entity once, and everywhere else I retrieve it from the repository.

Mechanics

- Create a repository for instances of the related object (if one isn't already present).
- Ensure the constructor has a way of looking up the correct instance of the related object.
- Change the constructors for the host object to use the repository to obtain the related object. Test after each change.

Example

I'll begin with a class that represents orders, which I might create from an incoming JSON document. Part of the order data is a customer ID from which I'm creating a customer object.

```
class Order...
  constructor(data) {
    this._number = data.number;
    this._customer = new Customer(data.customer);
    // load other data
  }
  get customer() {return this._customer;}

class Customer...
  constructor(id) {
    this._id = id;
  }
  get id() {return this._id;}
```

The customer object I create this way is a value. If I have five orders that refer to the customer ID of 123, I'll have five separate customer objects. Any change I make to one of them will not be reflected in the others. Should I want to enrich the customer objects, perhaps by gathering data from a customer service, I'd have to update all five customers with the same data. Having duplicate objects like this always makes me nervous—it's confusing to have multiple objects representing the same entity, such as a customer. This problem is particularly awkward if the customer object is mutable, which can lead to inconsistencies between the customer objects.

If I want to use the same customer object each time, I'll need a place to store it. Exactly where to store entities like this will vary from application to application, but for a simple case I like to use a repository object [\[mf-repos\]](#).

```

let _repositoryData;

export function initialize() {
  _repositoryData = {};
  _repositoryData.customers = new Map();
}

export function registerCustomer(id) {
  if (!_repositoryData.customers.has(id))
    _repositoryData.customers.set(id, new Customer(id));
  return findCustomer(id);
}

export function findCustomer(id) {
  return _repositoryData.customers.get(id);
}

```

The repository allows me to register customer objects with an ID and ensures I only create one customer object with the same ID. With this in place, I can change the order's constructor to use it.

Often, when doing this refactoring, the repository already exists, so I can just use it.

The next step is to figure out how the constructor for the order can obtain the correct customer object. In this case it's easy, since the customer's ID is present in the input data stream.

class Order...

```

constructor(data) {
  this._number = data.number;
  this._customer = registerCustomer(data.customer);
  // load other data
}
get customer() {return this._customer;}

```

Now, any changes I make to the customer of one order will be synchronized across all the orders sharing the same customer.

For this example, I created a new customer object with the first order that referenced it. Another common approach is to get a list of customers, populate the repository with them, and then link to them as I read the orders. In that case, an order that contains a customer ID not in the repository would indicate an error.

One problem with this code is that the constructor body is coupled to the global repository. Globals should be treated with care—like a powerful drug, they can be beneficial in small doses but a poison if used too much. If I'm concerned about it, I can pass the repository as a parameter to the constructor.

Chapter 10

Simplifying Conditional Logic

Much of the power of programs comes from their ability to implement conditional logic—but, sadly, much of the complexity of programs lies in these conditionals. I often use refactoring to make conditional sections easier to understand. I regularly apply *Decompose Conditional* (260) to complicated conditionals, and I use *Consolidate Conditional Expression* (263) to make logical combinations clearer. I use *Replace Nested Conditional with Guard Clauses* (266) to clarify cases where I want to run some pre-checks before my main processing. If I see several conditions using the same switching logic, it's a good time to pull *Replace Conditional with Polymorphism* (272) out the box.

A lot of conditionals are used to handle special cases, such as nulls; if that logic is mostly the same, then *Introduce Special Case* (289) (often referred to as *Introduce Null Object* (289)) can remove a lot of duplicate code. And, although I like to remove conditions a lot, if I want to communicate (and check) a program's state, I find *Introduce Assertion* (302) a worthwhile addition.

Decompose Conditional



```
if (!aDate.isBefore(plan.summerStart) && !aDate.isAfter(plan.summerEnd))
    charge = quantity * plan.summerRate;
else
    charge = quantity * plan.regularRate + plan.regularServiceCharge;
```



```
if (summer())
    charge = summerCharge();
else
    charge = regularCharge();
```

Motivation

One of the most common sources of complexity in a program is complex conditional logic. As I write code to do various things depending on various conditions, I can quickly end up with a pretty long function. Length of a function is in itself a factor that makes it harder to read, but conditions increase the difficulty. The problem usually lies in the fact that the code, both in the condition checks and in the actions, tells me what happens but can easily obscure *why* it happens.

As with any large block of code, I can make my intention clearer by decomposing it and replacing each chunk of code with a function call named after the intention of that chunk. With conditions, I particularly like doing this for the conditional part and each of the alternatives. This way, I highlight the condition and make it clear what I'm branching on. I also highlight the reason for the branching.

This is really just a particular case of applying *Extract Function (106)* to my code, but I like to highlight this case as one where I've often found a remarkably good value for the exercise.

Mechanics

- Apply *Extract Function (106)* on the condition and each leg of the conditional.

Example

Suppose I'm calculating the charge for something that has separate rates for winter and summer:

```
if (!aDate.isBefore(plan.summerStart) && !aDate.isAfter(plan.summerEnd))
  charge = quantity * plan.summerRate;
else
  charge = quantity * plan.regularRate + plan.regularServiceCharge;
```

I extract the condition into its own function.

```
if (summer())
  charge = quantity * plan.summerRate;
else
  charge = quantity * plan.regularRate + plan.regularServiceCharge;

function summer() {
  return !aDate.isBefore(plan.summerStart) && !aDate.isAfter(plan.summerEnd);
}
```

Then I do the then leg:

```
if (summer())
  charge = summerCharge();
else
  charge = quantity * plan.regularRate + plan.regularServiceCharge;

function summer() {
  return !aDate.isBefore(plan.summerStart) && !aDate.isAfter(plan.summerEnd);
}
function summerCharge() {
  return quantity * plan.summerRate;
}
```

Finally, the else leg:

```
if (summer())
  charge = summerCharge();
else
  charge = regularCharge();

function summer() {
  return !aDate.isBefore(plan.summerStart) && !aDate.isAfter(plan.summerEnd);
}
function summerCharge() {
  return quantity * plan.summerRate;
}
function regularCharge() {
  return quantity * plan.regularRate + plan.regularServiceCharge;
}
```

With that done, I like to reformat the conditional using the ternary operator.

```
charge = summer() ? summerCharge() : regularCharge();

function summer() {
  return !aDate.isBefore(plan.summerStart) && !aDate.isAfter(plan.summerEnd);
}
function summerCharge() {
  return quantity * plan.summerRate;
}
function regularCharge() {
  return quantity * plan.regularRate + plan.regularServiceCharge;
}
```

Consolidate Conditional Expression



```
if (anEmployee.seniority < 2) return 0;  
if (anEmployee.monthsDisabled > 12) return 0;  
if (anEmployee.isPartTime) return 0;
```



```
if (isNotEligibleForDisability()) return 0;  
  
function isNotEligibleForDisability() {  
  return ((anEmployee.seniority < 2)  
    || (anEmployee.monthsDisabled > 12)  
    || (anEmployee.isPartTime));  
}
```

Motivation

Sometimes, I run into a series of conditional checks where each check is different yet the resulting action is the same. When I see this, I use `and` and `or` operators to consolidate them into a single conditional check with a single result.

Consolidating the conditional code is important for two reasons. First, it makes it clearer by showing that I'm really making a single check that combines other checks. The sequence has the same effect, but it looks like I'm carrying out a sequence of separate checks that just happen to be close together. The second reason I like to do this is that it often sets me up for *Extract Function* (106). Extracting a condition is one of the most useful things I can do to clarify my code. It replaces a statement of what I'm doing with why I'm doing it.

The reasons in favor of consolidating conditionals also point to the reasons against doing it. If I consider it to be truly independent checks that shouldn't be thought of as a single check, I don't do the refactoring.

Mechanics

- Ensure that none of the conditionals have any side effects.

If any do, use *Separate Query from Modifier (306)* on them first.

- Take two of the conditional statements and combine their conditions using a logical operator.

Sequences combine with *or*, nested if statements combine with *and*.

- Test.
- Repeat combining conditionals until they are all in a single condition.
- Consider using *Extract Function (106)* on the resulting condition.

Example

Perusing some code, I see the following:

```
function disabilityAmount(anEmployee) {  
  if (anEmployee.seniority < 2) return 0;  
  if (anEmployee.monthsDisabled > 12) return 0;  
  if (anEmployee.isPartTime) return 0;  
  // compute the disability amount
```

It's a sequence of conditional checks which all have the same result. Since the result is the same, I should combine these conditions into a single expression. For a sequence like this, I do it using an *or* operator.

```
function disabilityAmount(anEmployee) {  
  if ((anEmployee.seniority < 2)  
      || (anEmployee.monthsDisabled > 12)) return 0;  
  if (anEmployee.isPartTime) return 0;  
  // compute the disability amount
```

I test, then fold in the other condition:

```
function disabilityAmount(anEmployee) {  
  if ((anEmployee.seniority < 2)  
      || (anEmployee.monthsDisabled > 12)  
      || (anEmployee.isPartTime)) return 0;  
  // compute the disability amount
```

Once I have them all together, I use *Extract Function (106)* on the condition.

```
function disabilityAmount(anEmployee) {  
  if (isNotEligableForDisability()) return 0;  
  // compute the disability amount  
  
  function isNotEligableForDisability() {  
    return ((anEmployee.seniority < 2)  
            || (anEmployee.monthsDisabled > 12)  
            || (anEmployee.isPartTime));  
  }  
}
```

Example: Using ands

The example above showed combining statements with an or, but I may run into cases that need ands as well. Such a case uses nested if statements:

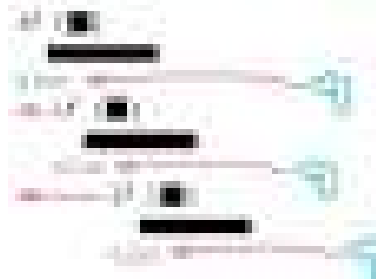
```
if (anEmployee.onVacation)  
  if (anEmployee.seniority > 10)  
    return 1;  
return 0.5;
```

I combine these using and operators.

```
if ((anEmployee.onVacation)  
    && (anEmployee.seniority > 10)) return 1;  
return 0.5;
```

If I have a mix of these, I can combine using and and or operators as needed. When this happens, things are likely to get messy, so I use *Extract Function (106)* liberally to make it all understandable.

Replace Nested Conditional with Guard Clauses



```
function getPayAmount() {
  let result;
  if (isDead)
    result = deadAmount();
  else {
    if (isSeparated)
      result = separatedAmount();
    else {
      if (isRetired)
        result = retiredAmount();
      else
        result = normalPayAmount();
    }
  }
  return result;
}
```



```
function getPayAmount() {
  if (isDead) return deadAmount();
  if (isSeparated) return separatedAmount();
  if (isRetired) return retiredAmount();
  return normalPayAmount();
}
```


Motivation

I often find that conditional expressions come in two styles. In the first style, both legs of the conditional are part of normal behavior, while in the second style, one leg is normal and the other indicates an unusual condition.

These kinds of conditionals have different intentions—and these intentions should come through in the code. If both are part of normal behavior, I use a condition with an `if` and an `else` leg. If the condition is an unusual condition, I check the condition and return if it's true. This kind of check is often called a **guard clause**.

The key point of Replace Nested Conditional with Guard Clauses is emphasis. If I'm using an `if-then-else` construct, I'm giving equal weight to the `if` leg and the `else` leg. This communicates to the reader that the legs are equally likely and important. Instead, the guard clause says, "This isn't the core to this function, and if it happens, do something and get out."

I often find I use Replace Nested Conditional with Guard Clauses when I'm working with a programmer who has been taught to have only one entry point and one exit point from a method. One entry point is enforced by modern languages, but one exit point is really not a useful rule. Clarity is the key principle: If the method is clearer with one exit point, use one exit point; otherwise don't.

Mechanics

- Select outermost condition that needs to be replaced, and change it into a guard clause.
- Test.
- Repeat as needed.
- If all the guard clauses return the same result, use *Consolidate Conditional Expression* (263).

Example

Here's some code to calculate a payment amount for an employee. It's only relevant if the employee is still with the company, so it has to check for the two other cases.

```
function payAmount(employee) {
  let result;
  if(employee.isSeparated) {
    result = {amount: 0, reasonCode: "SEP"};
  }
  else {
    if (employee.isRetired) {
      result = {amount: 0, reasonCode: "RET"};
    }
    else {
      // logic to compute amount
      lorem.ipsum(dolor.sitAmet);
      consectetur(adipiscing).elit();
      sed.do.eiusmod = tempor.incidunt.ut(labore) && dolore(magna.aliqua);
      ut.enim.ad(minim.veniam);
      result = someFinalComputation();
    }
  }
  return result;
}
```

Nesting the conditionals here masks the true meaning of what it going on. The primary purpose of this code only applies if these conditions aren't the case. In this situation, the intention of the code reads more clearly with guard clauses.

As with any refactoring change, I like to take small steps, so I begin with the topmost condition.

```
function payAmount(employee) {
  let result;
  if (employee.isSeparated) return {amount: 0, reasonCode: "SEP"};
  if (employee.isRetired) {
    result = {amount: 0, reasonCode: "RET"};
  }
  else {
    // logic to compute amount
    lorem.ipsum(dolor.sitAmet);
    consectetur(adipiscing).elit();
    sed.do.eiusmod = tempor.incidunt.ut(labore) && dolore(magna.aliqua);
    ut.enim.ad(minim.veniam);
    result = someFinalComputation();
  }
  return result;
}
```

I test that change and move on to the next one.

```
function payAmount(employee) {
  let result;
  if (employee.isSeparated) return {amount: 0, reasonCode: "SEP"};
  if (employee.isRetired) return {amount: 0, reasonCode: "RET"};
  // logic to compute amount
  lorem.ipsum(dolor.sitAmet);
  consectetur(adipiscing).elit();
  sed.do.eiusmod = tempor.incidunt.ut(labore) && dolore(magna.aliqua);
  ut.enim.ad(minim.veniam);
  result = someFinalComputation();
  return result;
}
```

At which point the result variable isn't really doing anything useful, so I remove it.

```
function payAmount(employee) {
  let result;
  if (employee.isSeparated) return {amount: 0, reasonCode: "SEP"};
  if (employee.isRetired) return {amount: 0, reasonCode: "RET"};
  // logic to compute amount
  lorem.ipsum(dolor.sitAmet);
  consectetur(adipiscing).elit();
  sed.do.eiusmod = tempor.incidunt.ut(labore) && dolore(magna.aliqua);
  ut.enim.ad(minim.veniam);
  return someFinalComputation();
}
```

The rule is that you always get an extra strawberry when you remove a mutable variable.

Example: Reversing the Conditions

When reviewing the manuscript of the first edition of this book, Joshua Kerievsky pointed out that we often do Replace Nested Conditional with Guard Clauses by reversing the conditional expressions. Even better, he gave me an example so I didn't have to further tax my imagination.

```
function adjustedCapital(anInstrument) {
  let result = 0;
  if (anInstrument.capital > 0) {
    if (anInstrument.interestRate > 0 && anInstrument.duration > 0) {
      result = (anInstrument.income / anInstrument.duration) * anInstrument.adjustmentFactor;
    }
  }
  return result;
}
```

Again, I make the replacements one at a time, but this time I reverse the condition as I put in the guard clause.

```
function adjustedCapital(anInstrument) {
  let result = 0;
  if (anInstrument.capital <= 0) return result;
  if (anInstrument.interestRate > 0 && anInstrument.duration > 0) {
    result = (anInstrument.income / anInstrument.duration) * anInstrument.adjustmentFactor;
  }
  return result;
}
```

The next conditional is a bit more complicated, so I do it in two steps. First, I simply add a not.

```
function adjustedCapital(anInstrument) {
  let result = 0;
  if (anInstrument.capital <= 0) return result;
  if (!(anInstrument.interestRate > 0 && anInstrument.duration > 0)) return result;
  result = (anInstrument.income / anInstrument.duration) * anInstrument.adjustmentFactor;
  return result;
}
```

Leaving nots in a conditional like that twists my mind around at a painful angle, so I simplify it:

```
function adjustedCapital(anInstrument) {
  let result = 0;
  if (anInstrument.capital <= 0) return result;
  if (anInstrument.interestRate <= 0 || anInstrument.duration <= 0) return result;
  result = (anInstrument.income / anInstrument.duration) * anInstrument.adjustmentFactor;
  return result;
}
```

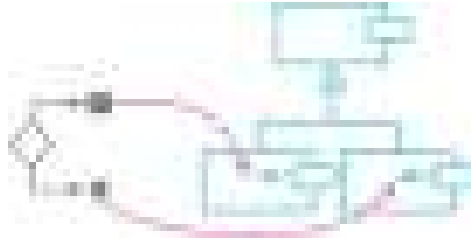
Both of those lines have conditions with the same result, so I apply *Consolidate Conditional Expression* (263).

```
function adjustedCapital(anInstrument) {
  let result = 0;
  if (
    anInstrument.capital <= 0
    || anInstrument.interestRate <= 0
    || anInstrument.duration <= 0
  ) return result;
  result = (anInstrument.income / anInstrument.duration) * anInstrument.adjustmentFactor;
  return result;
}
```

The result variable is doing two things here. Its first setting to zero indicates what to return when the guard clause triggers; its second value is the final computation. I can get rid of it, which both eliminates its double usage and gets me a strawberry.

```
function adjustedCapital(anInstrument) {  
  if (  anInstrument.capital    <= 0  
      || anInstrument.interestRate <= 0  
      || anInstrument.duration   <= 0) return 0;  
  return (anInstrument.income / anInstrument.duration) * anInstrument.adjustmentFactor;  
}
```

Replace Conditional with Polymorphism



```
switch (bird.type) {  
  case 'EuropeanSwallow':  
    return "average";  
  case 'AfricanSwallow':  
    return (bird.numberOfCoconuts > 2) ? "tired" : "average";  
  case 'NorwegianBlueParrot':  
    return (bird.voltage > 100) ? "scorched" : "beautiful";  
  default:  
    return "unknown";  
}
```



```
class EuropeanSwallow {  
  get plumage() {  
    return "average";  
  }  
}  
class AfricanSwallow {  
  get plumage() {  
    return (this.numberOfCoconuts > 2) ? "tired" : "average";  
  }  
}  
class NorwegianBlueParrot {  
  get plumage() {  
    return (this.voltage > 100) ? "scorched" : "beautiful";  
  }  
}
```

Motivation

Complex conditional logic is one of the hardest things to reason about in programming, so I always look for ways to add structure to conditional logic. Often, I find I can separate the logic into different circumstances—high-level cases—to

divide the conditions. Sometimes it's enough to represent this division within the structure of a conditional itself, but using classes and polymorphism can make the separation more explicit.

A common case for this is where I can form a set of types, each handling the conditional logic differently. I might notice that books, music, and food vary in how they are handled because of their type. This is made most obvious when there are several functions that have a switch statement on a type code. In that case, I remove the duplication of the common switch logic by creating classes for each case and using polymorphism to bring out the type-specific behavior.

Another situation is where I can think of the logic as a base case with variants. The base case may be the most common or most straightforward. I can put this logic into a superclass which allows me to reason about it without having to worry about the variants. I then put each variant case into a subclass, which I express with code that emphasizes its difference from the base case.

Polymorphism is one of the key features of object-oriented programming—and, like any useful feature, it's prone to overuse. I've come across people who argue that all examples of conditional logic should be replaced with polymorphism. I don't agree with that view. Most of my conditional logic uses basic conditional statements—if/else and switch/case. But when I see complex conditional logic that can be improved as discussed above, I find polymorphism a powerful tool.

Mechanics

- If classes do not exist for polymorphic behavior, create them together with a factory function to return the correct instance.
- Use the factory function in calling code.
- Move the conditional function to the superclass.

If the conditional logic is not a self-contained function, use *Extract Function* (106) to make it so.

- Pick one of the subclasses. Create a subclass method that overrides the conditional statement method. Copy the body of that leg of the conditional statement into the subclass method and adjust it to fit.
- Repeat for each leg of the conditional.
- Leave a default case for the superclass method. Or, if superclass should be abstract, declare that method as abstract or throw an error to show it should be the responsibility of a subclass.

Example

My friend has a collection of birds and wants to know how fast they can fly and what they have for plumage. So we have a couple of small programs to determine the information.

```
function plumages(birds) {
  return new Map(birds.map(b => [b.name, plumage(b)]));
}

function speeds(birds) {
  return new Map(birds.map(b => [b.name, airSpeedVelocity(b)]));
}

function plumage(bird) {
  switch (bird.type) {
    case 'EuropeanSwallow':
      return "average";
    case 'AfricanSwallow':
      return (bird.numberOfCoconuts > 2) ? "tired" : "average";
    case 'NorwegianBlueParrot':
      return (bird.voltage > 100) ? "scorched" : "beautiful";
    default:
      return "unknown";
  }
}

function airSpeedVelocity(bird) {
  switch (bird.type) {
    case 'EuropeanSwallow':
      return 35;
    case 'AfricanSwallow':
      return 40 - 2 * bird.numberOfCoconuts;
    case 'NorwegianBlueParrot':
      return (bird.isNailed) ? 0 : 10 + bird.voltage / 10;
    default:
      return null;
  }
}
```

We have a couple of different operations that vary with the type of bird, so it makes sense to create classes and use polymorphism for any type-specific behavior.

I begin by using *Combine Functions into Class (144)* on `airSpeedVelocity` and `plumage`.

```
function plumage(bird) {
  return new Bird(bird).plumage;
}

function airSpeedVelocity(bird) {
  return new Bird(bird).airSpeedVelocity;
}
```



```

class Bird {
  constructor(birdObject) {
    Object.assign(this, birdObject);
  }
  get plumage() {
    switch (this.type) {
      case 'EuropeanSwallow':
        return "average";
      case 'AfricanSwallow':
        return (this.numberOfCoconuts > 2) ? "tired" : "average";
      case 'NorwegianBlueParrot':
        return (this.voltage > 100) ? "scorched" : "beautiful";
      default:
        return "unknown";
    }
  }
  get airSpeedVelocity() {
    switch (this.type) {
      case 'EuropeanSwallow':
        return 35;
      case 'AfricanSwallow':
        return 40 - 2 * this.numberOfCoconuts;
      case 'NorwegianBlueParrot':
        return (this.isNailed) ? 0 : 10 + this.voltage / 10;
      default:
        return null;
    }
  }
}

```

I now add subclasses for each kind of bird, together with a factory function to instantiate the appropriate subclass.

```

function plumage(bird) {
  return createBird(bird).plumage;
}

function airSpeedVelocity(bird) {
  return createBird(bird).airSpeedVelocity;
}

function createBird(bird) {
  switch (bird.type) {
    case 'EuropeanSwallow':
      return new EuropeanSwallow(bird);
    case 'AfricanSwallow':
      return new AfricanSwallow(bird);
    case 'NorwegianBlueParrot':
      return new NorwegianBlueParrot(bird);
    default:
      return new Bird(bird);
  }
}

```

```

class EuropeanSwallow extends Bird {
}

class AfricanSwallow extends Bird {
}

class NorwegianBlueParrot extends Bird {
}

```

Now that I've created the class structure that I need, I can begin on the two conditional methods. I'll begin with plumage. I take one leg of the switch statement and override it in the appropriate subclass.

class EuropeanSwallow...

```

get plumage() {
    return "average";
}

```

class Bird...

```

get plumage() {
    switch (this.type) {
    case 'EuropeanSwallow':
        throw "oops";
    case 'AfricanSwallow':
        return (this.numberOfCoconuts > 2) ? "tired" : "average";
    case 'NorwegianBlueParrot':
        return (this.voltage > 100) ? "scorched" : "beautiful";
    default:
        return "unknown";
    }
}

```

I put in the throw because I'm paranoid.

I can compile and test at this point. Then, if all is well, I do the next leg.

class AfricanSwallow...

```

get plumage() {
    return (this.numberOfCoconuts > 2) ? "tired" : "average";
}

```

Then, the Norwegian Blue:

class NorwegianBlueParrot...

```

get plumage() {
    return (this.voltage > 100) ? "scorched" : "beautiful";
}

```

I leave the superclass method for the default case.

class Bird...

```
get plumage() {
  return "unknown";
}
```

I repeat the same process for `airSpeedVelocity`. Once I'm done, I end up with the following code (I also inlined the top-level functions for `airSpeedVelocity` and `plumage`):

```
function plumages(birds) {
  return new Map(birds
    .map(b => createBird(b))
    .map(bird => [bird.name, bird.plumage]));
}
function speeds(birds) {
  return new Map(birds
    .map(b => createBird(b))
    .map(bird => [bird.name, bird.airSpeedVelocity]));
}

function createBird(bird) {
  switch (bird.type) {
    case 'EuropeanSwallow':
      return new EuropeanSwallow(bird);
    case 'AfricanSwallow':
      return new AfricanSwallow(bird);
    case 'NorwegianBlueParrot':
      return new NorwegianBlueParrot(bird);
    default:
      return new Bird(bird);
  }
}

class Bird {
  constructor(birdObject) {
    Object.assign(this, birdObject);
  }
  get plumage() {
    return "unknown";
  }
  get airSpeedVelocity() {
    return null;
  }
}

class EuropeanSwallow extends Bird {
  get plumage() {
    return "average";
  }
  get airSpeedVelocity() {
    return 35;
  }
}
```

```
class AfricanSwallow extends Bird {
  get plumage() {
    return (this.numberOfCoconuts > 2) ? "tired" : "average";
  }
  get airSpeedVelocity() {
    return 40 - 2 * this.numberOfCoconuts;
  }
}
class NorwegianBlueParrot extends Bird {
  get plumage() {
    return (this.voltage > 100) ? "scorched" : "beautiful";
  }
  get airSpeedVelocity() {
    return (this.isNailed) ? 0 : 10 + this.voltage / 10;
  }
}
```

Looking at this final code, I can see that the superclass `Bird` isn't strictly needed. In JavaScript, I don't need a type hierarchy for polymorphism; as long as my objects implement the appropriately named methods, everything works fine. In this situation, however, I like to keep the unnecessary superclass as it helps explain the way the classes are related in the domain.

Example: Using Polymorphism for Variation

With the birds example, I'm using a clear generalization hierarchy. That's how subclassing and polymorphism is often discussed in textbooks (including mine)—but it's not the only way inheritance is used in practice; indeed, it probably isn't the most common or best way. Another case for inheritance is when I wish to indicate that one object is mostly similar to another, but with some variations.

As an example of this case, consider some code used by a rating agency to compute an investment rating for the voyages of sailing ships. The rating agency gives out either an "A" or "B" rating, depending of various factors due to risk and profit potential. The risk comes from assessing the nature of the voyage as well as the history of the captain's prior voyages.

```
function rating(voyage, history) {
  const vpf = voyageProfitFactor(voyage, history);
  const vr = voyageRisk(voyage);
  const chr = captainHistoryRisk(voyage, history);
  if (vpf * 3 > (vr + chr * 2)) return "A";
  else return "B";
}
```

```

function voyageRisk(voyage) {
  let result = 1;
  if (voyage.length > 4) result += 2;
  if (voyage.length > 8) result += voyage.length - 8;
  if ([ "china", "east-indies" ].includes(voyage.zone)) result += 4;
  return Math.max(result, 0);
}
function captainHistoryRisk(voyage, history) {
  let result = 1;
  if (history.length < 5) result += 4;
  result += history.filter(v => v.profit < 0).length;
  if (voyage.zone === "china" && hasChina(history)) result -= 2;
  return Math.max(result, 0);
}
function hasChina(history) {
  return history.some(v => "china" === v.zone);
}
function voyageProfitFactor(voyage, history) {
  let result = 2;
  if (voyage.zone === "china") result += 1;
  if (voyage.zone === "east-indies") result += 1;
  if (voyage.zone === "china" && hasChina(history)) {
    result += 3;
    if (history.length > 10) result += 1;
    if (voyage.length > 12) result += 1;
    if (voyage.length > 18) result -= 1;
  }
  else {
    if (history.length > 8) result += 1;
    if (voyage.length > 14) result -= 1;
  }
  return result;
}

```

The functions `voyageRisk` and `captainHistoryRisk` score points for risk, `voyageProfitFactor` scores points for the potential profit, and `rating` combines these to give the overall rating for the voyage.

The calling code would look something like this:

```

const voyage = {zone: "west-indies", length: 10};
const history = [
  {zone: "east-indies", profit: 5},
  {zone: "west-indies", profit: 15},
  {zone: "china", profit: -2},
  {zone: "west-africa", profit: 7},
];

const myRating = rating(voyage, history);

```

What I want to focus on here is how a couple of places use conditional logic to handle the case of a voyage to China where the captain has been to China before.

```
function rating(voyage, history) {
  const vpf = voyageProfitFactor(voyage, history);
  const vr = voyageRisk(voyage);
  const chr = captainHistoryRisk(voyage, history);
  if (vpf * 3 > (vr + chr * 2)) return "A";
  else return "B";
}

function voyageRisk(voyage) {
  let result = 1;
  if (voyage.length > 4) result += 2;
  if (voyage.length > 8) result += voyage.length - 8;
  if (["china", "east-indies"].includes(voyage.zone)) result += 4;
  return Math.max(result, 0);
}

function captainHistoryRisk(voyage, history) {
  let result = 1;
  if (history.length < 5) result += 4;
  result += history.filter(v => v.profit < 0).length;
  if (voyage.zone === "china" && hasChina(history)) result -= 2;
  return Math.max(result, 0);
}

function hasChina(history) {
  return history.some(v => "china" === v.zone);
}

function voyageProfitFactor(voyage, history) {
  let result = 2;
  if (voyage.zone === "china") result += 1;
  if (voyage.zone === "east-indies") result += 1;
  if (voyage.zone === "china" && hasChina(history)) {
    result += 3;
    if (history.length > 10) result += 1;
    if (voyage.length > 12) result += 1;
    if (voyage.length > 18) result -= 1;
  }
  else {
    if (history.length > 8) result += 1;
    if (voyage.length > 14) result -= 1;
  }
  return result;
}
```

I will use inheritance and polymorphism to separate out the logic for handling these cases from the base logic. This is a particularly useful refactoring if I'm about to introduce more special logic for this case—and the logic for these repeat China voyages can make it harder to understand the base case.

I'm beginning with a set of functions. To introduce polymorphism, I need to create a class structure, so I begin by applying *Combine Functions into Class (144)*. This results in the following code:

```
function rating(voyage, history) {
  return new Rating(voyage, history).value;
}

class Rating {
  constructor(voyage, history) {
    this.voyage = voyage;
    this.history = history;
  }
  get value() {
    const vp = this.voyageProfitFactor;
    const vr = this.voyageRisk;
    const chr = this.captainHistoryRisk;
    if (vp * 3 > (vr + chr * 2)) return "A";
    else return "B";
  }
  get voyageRisk() {
    let result = 1;
    if (this.voyage.length > 4) result += 2;
    if (this.voyage.length > 8) result += this.voyage.length - 8;
    if (["china", "east-indies"].includes(this.voyage.zone)) result += 4;
    return Math.max(result, 0);
  }
  get captainHistoryRisk() {
    let result = 1;
    if (this.history.length < 5) result += 4;
    result += this.history.filter(v => v.profit < 0).length;
    if (this.voyage.zone === "china" && this.hasChinaHistory) result -= 2;
    return Math.max(result, 0);
  }
  get voyageProfitFactor() {
    let result = 2;

    if (this.voyage.zone === "china") result += 1;
    if (this.voyage.zone === "east-indies") result += 1;
    if (this.voyage.zone === "china" && this.hasChinaHistory) {
      result += 3;
      if (this.history.length > 10) result += 1;
      if (this.voyage.length > 12) result += 1;
      if (this.voyage.length > 18) result -= 1;
    }
    else {
      if (this.history.length > 8) result += 1;
      if (this.voyage.length > 14) result -= 1;
    }
    return result;
  }
}
```

```

    get hasChinaHistory() {
      return this.history.some(v => "china" === v.zone);
    }
  }
}

```

That's given me the class for the base case. I now need to create an empty subclass to house the variant behavior.

```

class ExperiencedChinaRating extends Rating {
}

```

I then create a factory function to return the variant class when needed.

```

function createRating(voyage, history) {
  if (voyage.zone === "china" && history.some(v => "china" === v.zone))
    return new ExperiencedChinaRating(voyage, history);
  else return new Rating(voyage, history);
}

```

I need to modify any callers to use the factory function instead of directly invoking the constructor, which in this case is just the rating function.

```

function rating(voyage, history) {
  return createRating(voyage, history).value;
}

```

There are two bits of behavior I need to move into a subclass. I begin with the logic in `captainHistoryRisk`:

class Rating...

```

get captainHistoryRisk() {
  let result = 1;
  if (this.history.length < 5) result += 4;
  result += this.history.filter(v => v.profit < 0).length;
  if (this.voyage.zone === "china" && this.hasChinaHistory) result -= 2;
  return Math.max(result, 0);
}

```

I write the overriding method in the subclass:

class ExperiencedChinaRating

```

get captainHistoryRisk() {
  const result = super.captainHistoryRisk - 2;
  return Math.max(result, 0);
}

```


class Rating...

```
get captainHistoryRisk() {
  let result = 1;
  if (this.history.length < 5) result += 4;
  result += this.history.filter(v => v.profit < 0).length;
  if (this.voyage.zone === "china" && this.hasChinaHistory) result -= 2;
  return Math.max(result, 0);
}
```

Separating the variant behavior from `voyageProfitFactor` is a bit more messy. I can't simply remove the variant behavior and call the superclass method since there is an alternative path here. I also don't want to copy the whole superclass method down to the subclass.

class Rating...

```
get voyageProfitFactor() {
  let result = 2;

  if (this.voyage.zone === "china") result += 1;
  if (this.voyage.zone === "east-indies") result += 1;
  if (this.voyage.zone === "china" && this.hasChinaHistory) {
    result += 3;
    if (this.history.length > 10) result += 1;
    if (this.voyage.length > 12) result += 1;
    if (this.voyage.length > 18) result -= 1;
  }
  else {
    if (this.history.length > 8) result += 1;
    if (this.voyage.length > 14) result -= 1;
  }
  return result;
}
```

So my response is to first use *Extract Function (106)* on the entire conditional block.

class Rating...

```
get voyageProfitFactor() {
  let result = 2;

  if (this.voyage.zone === "china") result += 1;
  if (this.voyage.zone === "east-indies") result += 1;
  result += this.voyageAndHistoryLengthFactor;
  return result;
}
```

```

get voyageAndHistoryLengthFactor() {
  let result = 0;
  if (this.voyage.zone === "china" && this.hasChinaHistory) {
    result += 3;
    if (this.history.length > 10) result += 1;
    if (this.voyage.length > 12) result += 1;
    if (this.voyage.length > 18) result -= 1;
  }
  else {
    if (this.history.length > 8) result += 1;
    if (this.voyage.length > 14) result -= 1;
  }
  return result;
}

```

A function name with an “And” in it is a pretty bad smell, but I’ll let it sit and reek for a moment, while I apply the subclassing.

class Rating...

```

get voyageAndHistoryLengthFactor() {
  let result = 0;
  if (this.history.length > 8) result += 1;
  if (this.voyage.length > 14) result -= 1;
  return result;
}

```

class ExperiencedChinaRating...

```

get voyageAndHistoryLengthFactor() {
  let result = 0;
  result += 3;
  if (this.history.length > 10) result += 1;
  if (this.voyage.length > 12) result += 1;
  if (this.voyage.length > 18) result -= 1;
  return result;
}

```

That’s, formally, the end of the refactoring—I’ve separated the variant behavior out into the subclass. The superclass’s logic is simpler to understand and work with, and I only need to deal with variant case when I’m working on the subclass code, which is expressed in terms of its difference with the superclass.

But I feel I should at least outline what I’d do with the awkward new method. Introducing a method purely for overriding by a subclass is a common thing to do when doing this kind of base-and-variation inheritance. But a crude method like this obscures what’s going on, instead of revealing.

The “And” gives away that there are really two separate modifications going on here—so I think it’s wise to separate them. I’ll do this by using *Extract Function*

(106) on the history length modification, both in the superclass and subclass. I start with just the superclass:

class Rating...

```
get voyageAndHistoryLengthFactor() {
  let result = 0;
  result += this.historyLengthFactor;
  if (this.voyage.length > 14) result -= 1;
  return result;
}
get historyLengthFactor() {
  return (this.history.length > 8) ? 1 : 0;
}
```

I do the same with the subclass:

class ExperiencedChinaRating...

```
get voyageAndHistoryLengthFactor() {
  let result = 0;
  result += 3;
  result += this.historyLengthFactor;
  if (this.voyage.length > 12) result += 1;
  if (this.voyage.length > 18) result -= 1;
  return result;
}
get historyLengthFactor() {
  return (this.history.length > 10) ? 1 : 0;
}
```

I can then use *Move Statements to Callers* (217) on the superclass case.

class Rating...

```
get voyageProfitFactor() {
  let result = 2;
  if (this.voyage.zone === "china") result += 1;
  if (this.voyage.zone === "east-indies") result += 1;
  result += this.historyLengthFactor;
  result += this.voyageAndHistoryLengthFactor;
  return result;
}

get voyageAndHistoryLengthFactor() {
  let result = 0;
  result += this.historyLengthFactor;
  if (this.voyage.length > 14) result -= 1;
  return result;
}
```

```
class ExperiencedChinaRating...
  get voyageAndHistoryLengthFactor() {
    let result = 0;
    result += 3;
    result += this.historyLengthFactor;
    if (this.voyage.length > 12) result += 1;
    if (this.voyage.length > 18) result -= 1;
    return result;
  }
```

I'd then use *Rename Function* (124).

```
class Rating...
  get voyageProfitFactor() {
    let result = 2;
    if (this.voyage.zone === "china") result += 1;
    if (this.voyage.zone === "east-indies") result += 1;
    result += this.historyLengthFactor;
    result += this.voyageLengthFactor;
    return result;
  }

  get voyageLengthFactor() {
    return (this.voyage.length > 14) ? - 1: 0;
  }
```

Changing to a ternary to simplify voyageLengthFactor.

```
class ExperiencedChinaRating...
  get voyageLengthFactor() {
    let result = 0;
    result += 3;
    if (this.voyage.length > 12) result += 1;
    if (this.voyage.length > 18) result -= 1;
    return result;
  }
```

One last thing. I don't think adding 3 points makes sense as part of the voyage length factor—it's better added to the overall result.

```
class ExperiencedChinaRating...
  get voyageProfitFactor() {
    return super.voyageProfitFactor + 3;
  }

  get voyageLengthFactor() {
    let result = 0;
    result += 3;
    if (this.voyage.length > 12) result += 1;
    if (this.voyage.length > 18) result -= 1;
    return result;
  }
```

At the end of the refactoring, I have the following code. First, there is the basic rating class which can ignore any complications of the experienced China case:

```
class Rating {
  constructor(voyage, history) {
    this.voyage = voyage;
    this.history = history;
  }
  get value() {
    const vpf = this.voyageProfitFactor;
    const vr = this.voyageRisk;
    const chr = this.captainHistoryRisk;
    if (vpf * 3 > (vr + chr * 2)) return "A";
    else return "B";
  }
  get voyageRisk() {
    let result = 1;
    if (this.voyage.length > 4) result += 2;
    if (this.voyage.length > 8) result += this.voyage.length - 8;
    if (["china", "east-indies"].includes(this.voyage.zone)) result += 4;
    return Math.max(result, 0);
  }
  get captainHistoryRisk() {
    let result = 1;
    if (this.history.length < 5) result += 4;
    result += this.history.filter(v => v.profit < 0).length;
    return Math.max(result, 0);
  }
  get voyageProfitFactor() {
    let result = 2;
    if (this.voyage.zone === "china") result += 1;
    if (this.voyage.zone === "east-indies") result += 1;
    result += this.historyLengthFactor;
    result += this.voyageLengthFactor;
    return result;
  }
  get voyageLengthFactor() {
    return (this.voyage.length > 14) ? - 1 : 0;
  }
  get historyLengthFactor() {
    return (this.history.length > 8) ? 1 : 0;
  }
}
```

The code for the experienced China case reads as a set of variations on the base:

```
class ExperiencedChinaRating extends Rating {  
  get captainHistoryRisk() {  
    const result = super.captainHistoryRisk - 2;  
    return Math.max(result, 0);  
  }  
  get voyageLengthFactor() {  
    let result = 0;  
    if (this.voyage.length > 12) result += 1;  
    if (this.voyage.length > 18) result -= 1;  
    return result;  
  }  
  get historyLengthFactor() {  
    return (this.history.length > 10) ? 1 : 0;  
  }  
  get voyageProfitFactor() {  
    return super.voyageProfitFactor + 3;  
  }  
}
```

Introduce Special Case

formerly: *Introduce Null Object*



```
if (aCustomer === "unknown") customerName = "occupant";
```



```
class UnknownCustomer {  
  get name() {return "occupant";}  
}
```

Motivation

A common case of duplicated code is when many users of a data structure check a specific value, and then most of them do the same thing. If I find many parts of the code base having the same reaction to a particular value, I want to bring that reaction into a single place.

A good mechanism for this is the Special Case pattern where I create a special-case element that captures all the common behavior. This allows me to replace most of the special-case checks with simple calls.

A special case can manifest itself in several ways. If all I'm doing with the object is reading data, I can supply a literal object with all the values I need filled in. If I need more behavior than simple values, I can create a special object with methods for all the common behavior. The special-case object can be returned by an encapsulating class, or inserted into a data structure with a transform.

A common value that needs special-case processing is null, which is why this pattern is often called the Null Object pattern. But it's the same approach for any special case—I like to say that Null Object is a special case of Special Case.

Mechanics

Begin with a container data structure (or class) that contains a property which is the subject of the refactoring. Clients of the container compare the subject

property of the container to a special-case value. We wish to replace the special-case value of the subject with a special case class or data structure.

- Add a special-case check property to the subject, returning false.
- Create a special-case object with only the special-case check property, returning true.
- Apply *Extract Function (106)* to the special-case comparison code. Ensure that all clients use the new function instead of directly comparing it.
- Introduce the new special-case subject into the code, either by returning it from a function call or by applying a transform function.
- Change the body of the special-case comparison function so that it uses the special-case check property.
- Test.
- Use *Combine Functions into Class (144)* or *Combine Functions into Transform (149)* to move all of the common special-case behavior into the new element.

Since the special-case class usually returns fixed values to simple requests, these may be handled by making the special case a literal record.

- Use *Inline Function (115)* on the special-case comparison function for the places where it's still needed.

Example

A utility company installs its services in sites.

class Site...

```
get customer() {return this._customer;}
```

There are various properties of the customer class; I'll consider three of them.

class Customer...

```
get name()           {...}
get billingPlan()    {...}
set billingPlan(arg) {...}
get paymentHistory() {...}
```

Most of the time, a site has a customer, but sometimes there isn't one. Someone may have moved out and I don't yet know who, if anyone, has moved in. When this happens, the data record fills the customer field with the string "unknown". Because this can happen, clients of the site need to be able to handle an unknown customer. Here are some example fragments:

client 1...

```
const aCustomer = site.customer;
// ... lots of intervening code ...
let customerName;
if (aCustomer === "unknown") customerName = "occupant";
else customerName = aCustomer.name;
```

client 2...

```
const plan = (aCustomer === "unknown") ?
  registry.billingPlans.basic
  : aCustomer.billingPlan;
```

client 3...

```
if (aCustomer !== "unknown") aCustomer.billingPlan = newPlan;
```

client 4...

```
const weeksDelinquent = (aCustomer === "unknown") ?
  0
  : aCustomer.paymentHistory.weeksDelinquentInLastYear;
```

Looking through the code base, I see many clients of the site object that have to deal with an unknown customer. Most of them do the same thing when they get one: They use “occupant” as the name, give them a basic billing plan, and class them as zero-weeks delinquent. This widespread testing for a special case, plus a common response, is what tells me it’s time for a Special Case Object.

I begin by adding a method to the customer to indicate it is unknown.

class Customer...

```
get isUnknown() {return false;}
```

I then add an Unknown Customer class.

```
class UnknownCustomer {
  get isUnknown() {return true;}
}
```

Note that I don’t make UnknownCustomer a subclass of Customer. In other languages, particularly those statically typed, I would, but JavaScript’s rules for subclassing, as well as its dynamic typing, make it better to not do that here.

Now comes the tricky bit. I have to return this new special-case object whenever I expect “unknown” and change each test for an unknown value to use the new `isUnknown` method. In general, I always want to arrange things so I can make one small change at a time, then test. But if I change the customer class to return an unknown customer instead of “unknown”, I have to make every client testing for “unknown” to call `isUnknown`—and I have to do it all at once. I find that as appealing as eating liver (i.e., not at all).

There is a common technique to use whenever I find myself in this bind. I use *Extract Function (106)* on the code that I'd have to change in lots of places—in this case, the special-case comparison code.

```
function isUnknown(arg) {
  if (!(arg instanceof Customer) || (arg === "unknown"))
    throw new Error(`investigate bad value: <${arg}>`);
  return (arg === "unknown");
}
```

I've put a trap in here for an unexpected value. This can help me to spot any mistakes or odd behavior as I'm doing this refactoring.

I can now use this function whenever I'm testing for an unknown customer. I can change these calls one at a time, testing after each change.

client 1...

```
let customerName;
if (isUnknown(aCustomer)) customerName = "occupant";
else customerName = aCustomer.name;
```

After a while, I have done them all.

client 2...

```
const plan = (isUnknown(aCustomer)) ?
  registry.billingPlans.basic
  : aCustomer.billingPlan;
```

client 3...

```
if (!isUnknown(aCustomer)) aCustomer.billingPlan = newPlan;
```

client 4...

```
const weeksDelinquent = isUnknown(aCustomer) ?
  0
  : aCustomer.paymentHistory.weeksDelinquentInLastYear;
```

Once I've changed all the callers to use `isUnknown`, I can change the `Site` class to return an unknown customer.

class Site...

```
get customer() {
  return (this._customer === "unknown") ? new UnknownCustomer() : this._customer;
}
```

I can check that I'm no longer using the "unknown" string by changing `isUnknown` to use the unknown value.

client 1...

```
function isUnknown(arg) {
  if (!(arg instanceof Customer || arg instanceof UnknownCustomer))
    throw new Error(`investigate bad value: <${arg}>`);
  return arg.isUnknown;
}
```

I test to ensure that's all working.

Now the fun begins. I can use *Combine Functions into Class (144)* to take each client's special-case check and see if I can replace it with a commonly expected value. At the moment, I have various clients using "occupant" for the name of an unknown customer, like this:

client 1...

```
let customerName;
if (isUnknown(aCustomer)) customerName = "occupant";
else customerName = aCustomer.name;
```

I add a suitable method to the unknown customer:

class UnknownCustomer...

```
  get name() {return "occupant";}
```

Now I can make all that conditional code go away.

client 1...

```
const customerName = aCustomer.name;
```

Once I've tested that this works, I'll probably be able to use *Inline Variable (123)* on that variable too.

Next is the billing plan property.

client 2...

```
const plan = (isUnknown(aCustomer)) ?
  registry.billingPlans.basic
  : aCustomer.billingPlan;
```

client 3...

```
if (!isUnknown(aCustomer)) aCustomer.billingPlan = newPlan;
```

For read behavior, I do the same thing I did with the name—take the common response and reply with it. With the write behavior, the current code doesn't call the setter for an unknown customer—so for the special case, I let the setter be called, but it does nothing.

class UnknownCustomer...

```
get billingPlan() {return registry.billingPlans.basic;}
set billingPlan(arg) { /* ignore */ }
```

client reader...

```
const plan = aCustomer.billingPlan;
```

client writer...

```
aCustomer.billingPlan = newPlan;
```

Special-case objects are value objects, and thus should always be immutable, even if the objects they are substituting for are not.

The last case is a bit more involved because the special case needs to return another object that has its own properties.

client...

```
const weeksDelinquent = isUnknown(aCustomer) ?
    0
    : aCustomer.paymentHistory.weeksDelinquentInLastYear;
```

The general rule with a special-case object is that if it needs to return related objects, they are usually special cases themselves. So here I need to create a null payment history.

class UnknownCustomer...

```
get paymentHistory() {return new NullPaymentHistory();}
```

class NullPaymentHistory...

```
get weeksDelinquentInLastYear() {return 0;}
```

client...

```
const weeksDelinquent = aCustomer.paymentHistory.weeksDelinquentInLastYear;
```

I carry on, looking at all the clients to see if I can replace them with the polymorphic behavior. But there will be exceptions—clients that want to do something different with the special case. I may have 23 clients that use “occupant” for the name of an unknown customer, but there’s always one that needs something different.

client...

```
const name = ! isUnknown(aCustomer) ? aCustomer.name : "unknown occupant";
```

In that case, I need to retain a special-case check. I will change it to use the method on customer, essentially using *Inline Function (115)* on `isUnknown`.

client...

```
const name = aCustomer.isUnknown ? "unknown occupant" : aCustomer.name;
```

When I'm done with all the clients, I should be able to use *Remove Dead Code* (237) on the global `isPresent` function, as nobody should be calling it any more.

Example: Using an Object Literal

Creating a class like this is a fair bit of work for what is really a simple value. But for the example I gave, I had to make the class since the customer could be updated. If, however, I only read the data structure, I can use a literal object instead.

Here is the opening case again—just the same, except this time there is no client that updates the customer:

class Site...

```
  get customer() {return this._customer;}
```

class Customer...

```
  get name()           {...}
  get billingPlan()    {...}
  set billingPlan(arg) {...}
  get paymentHistory() {...}
```

client 1...

```
  const aCustomer = site.customer;
  // ... lots of intervening code ...
  let customerName;
  if (aCustomer === "unknown") customerName = "occupant";
  else customerName = aCustomer.name;
```

client 2...

```
  const plan = (aCustomer === "unknown") ?
    registry.billingPlans.basic
    : aCustomer.billingPlan;
```

client 3...

```
  const weeksDelinquent = (aCustomer === "unknown") ?
    0
    : aCustomer.paymentHistory.weeksDelinquentInLastYear;
```

As with the previous case, I start by adding an `isUnknown` property to the customer and creating a special-case object with that field. The difference is that this time, the special case is a literal.

class Customer...

```
  get isUnknown() {return false;}
```

top level...

```
function createUnknownCustomer() {
  return {
    isUnknown: true,
  };
}
```

I apply *Extract Function (106)* to the special case condition test.

```
function isUnknown(arg) {
  return (arg === "unknown");
}
```

client 1...

```
let customerName;
if (isUnknown(aCustomer)) customerName = "occupant";
else customerName = aCustomer.name;
```

client 2...

```
const plan = isUnknown(aCustomer) ?
  registry.billingPlans.basic
  : aCustomer.billingPlan;
```

client 3...

```
const weeksDelinquent = isUnknown(aCustomer) ?
  0
  : aCustomer.paymentHistory.weeksDelinquentInLastYear;
```

I change the site class and the condition test to work with the special case.

class Site...

```
get customer() {
  return (this._customer === "unknown") ? createUnknownCustomer() : this._customer;
}
```

top level...

```
function isUnknown(arg) {
  return arg.isUnknown;
}
```

Then I replace each standard response with the appropriate literal value. I start with the name:

```
function createUnknownCustomer() {
  return {
    isUnknown: true,
    name: "occupant",
  };
}
```

client 1...

```
const customerName = aCustomer.name;
```

Then, the billing plan:

```
function createUnknownCustomer() {  
  return {  
    isUnknown: true,  
    name: "occupant",  
    billingPlan: registry.billingPlans.basic,  
  };  
}
```

client 2...

```
const plan = aCustomer.billingPlan;
```

Similarly, I can create a nested null payment history with the literal:

```
function createUnknownCustomer() {  
  return {  
    isUnknown: true,  
    name: "occupant",  
    billingPlan: registry.billingPlans.basic,  
    paymentHistory: {  
      weeksDelinquentInLastYear: 0,  
    },  
  };  
}
```

client 3...

```
const weeksDelinquent = aCustomer.paymentHistory.weeksDelinquentInLastYear;
```

If I use a literal like this, I should make it immutable, which I might do with freeze. Usually, I'd rather use a class.

Example: Using a Transform

Both previous cases involve a class, but the same idea can be applied to a record by using a transform step.

Let's assume our input is a simple record structure that looks something like this:

```

{
  name: "Acme Boston",
  location: "Malden MA",
  // more site details
  customer: {
    name: "Acme Industries",
    billingPlan: "plan-451",
    paymentHistory: {
      weeksDelinquentInLastYear: 7
    },
    // more
  },
}

```

In some cases, the customer isn't known, and such cases are marked in the same way:

```

{
  name: "Warehouse Unit 15",
  location: "Malden MA",
  // more site details
  customer: "unknown",
}

```

I have similar client code that checks for the unknown customer:

client 1...

```

const site = acquireSiteData();
const aCustomer = site.customer;
// ... lots of intervening code ...
let customerName;
if (aCustomer === "unknown") customerName = "occupant";
else customerName = aCustomer.name;

```

client 2...

```

const plan = (aCustomer === "unknown") ?
  registry.billingPlans.basic
  : aCustomer.billingPlan;

```

client 3...

```

const weeksDelinquent = (aCustomer === "unknown") ?
  0
  : aCustomer.paymentHistory.weeksDelinquentInLastYear;

```

My first step is to run the site data structure through a transform that, currently, does nothing but a deep copy.

client 1...

```
const rawSite = acquireSiteData();
const site = enrichSite(rawSite);
const aCustomer = site.customer;
// ... lots of intervening code ...
let customerName;
if (aCustomer === "unknown") customerName = "occupant";
else customerName = aCustomer.name;

function enrichSite(inputSite) {
  return _.cloneDeep(inputSite);
}
```

I apply *Extract Function (106)* to the test for an unknown customer.

```
function isUnknown(aCustomer) {
  return aCustomer === "unknown";
}
```

client 1...

```
const rawSite = acquireSiteData();
const site = enrichSite(rawSite);
const aCustomer = site.customer;
// ... lots of intervening code ...
let customerName;
if (isUnknown(aCustomer)) customerName = "occupant";
else customerName = aCustomer.name;
```

client 2...

```
const plan = (isUnknown(aCustomer)) ?
  registry.billingPlans.basic
  : aCustomer.billingPlan;
```

client 3...

```
const weeksDelinquent = (isUnknown(aCustomer)) ?
  0
  : aCustomer.paymentHistory.weeksDelinquentInLastYear;
```

I begin the enrichment by adding an `isUnknown` property to the customer.

```
function enrichSite(aSite) {
  const result = _.cloneDeep(aSite);
  const unknownCustomer = {
    isUnknown: true,
  };

  if (isUnknown(result.customer)) result.customer = unknownCustomer;
  else result.customer.isUnknown = false;
  return result;
}
```

I can then modify the special-case condition test to include probing for this new property. I keep the original test as well, so that the test will work on both raw and enriched sites.

```
function isUnknown(aCustomer) {
  if (aCustomer === "unknown") return true;
  else return aCustomer.isUnknown;
}
```

I test to ensure that's all OK, then start applying *Combine Functions into Transform (149)* on the special case. First, I move the choice of name into the enrichment function.

```
function enrichSite(aSite) {
  const result = _.cloneDeep(aSite);
  const unknownCustomer = {
    isUnknown: true,
    name: "occupant",
  };

  if (isUnknown(result.customer)) result.customer = unknownCustomer;
  else result.customer.isUnknown = false;
  return result;
}
```

client 1...

```
const rawSite = acquireSiteData();
const site = enrichSite(rawSite);
const aCustomer = site.customer;
// ... lots of intervening code ...
const customerName = aCustomer.name;
```

I test, then do the billing plan.

```
function enrichSite(aSite) {
  const result = _.cloneDeep(aSite);
  const unknownCustomer = {
    isUnknown: true,
    name: "occupant",
    billingPlan: registry.billingPlans.basic,
  };

  if (isUnknown(result.customer)) result.customer = unknownCustomer;
  else result.customer.isUnknown = false;
  return result;
}
```

client 2...

```
const plan = aCustomer.billingPlan;
```

I test again, then do the last client.

```
function enrichSite(aSite) {  
  const result = _.cloneDeep(aSite);  
  const unknownCustomer = {  
    isUnknown: true,  
    name: "occupant",  
    billingPlan: registry.billingPlans.basic,  
    paymentHistory: {  
      weeksDelinquentInLastYear: 0,  
    }  
  };  
  
  if (isUnknown(result.customer)) result.customer = unknownCustomer;  
  else result.customer.isUnknown = false;  
  return result;  
}
```

client 3...

```
const weeksDelinquent = aCustomer.paymentHistory.weeksDelinquentInLastYear;
```

Introduce Assertion



```
if (this.discountRate)
    base = base - (this.discountRate * base);
```



```
assert(this.discountRate >= 0);
if (this.discountRate)
    base = base - (this.discountRate * base);
```

Motivation

Often, sections of code work only if certain conditions are true. This may be as simple as a square root calculation only working on a positive input value. With an object, it may require that at least one of a group of fields has a value in it.

Such assumptions are often not stated but can only be deduced by looking through an algorithm. Sometimes, the assumptions are stated with a comment. A better technique is to make the assumption explicit by writing an assertion.

An assertion is a conditional statement that is assumed to be always true. Failure of an assertion indicates a programmer error. Assertion failures should never be checked by other parts of the system. Assertions should be written so that the program functions equally correctly if they are all removed; indeed, some languages provide assertions that can be disabled by a compile-time switch.

I often see people encourage using assertions in order to find errors. While this is certainly a Good Thing, it's not the only reason to use them. I find assertions to be a valuable form of communication—they tell the reader something about the assumed state of the program at this point of execution. I also find them handy for debugging, and their communication value means I'm inclined to leave them in once I've fixed the error I'm chasing. Self-testing code reduces their value for debugging, as steadily narrowing unit tests often do the job better, but I still like assertions for communication.

Mechanics

- When you see that a condition is assumed to be true, add an assertion to state it.

Since assertions should not affect the running of a system, adding one is always behavior-preserving.

Example

Here's a simple tale of discounts. A customer can be given a discount rate to apply to all their purchases:

class Customer...

```
    applyDiscount(aNumber) {
        return (this.discountRate
            ? aNumber - (this.discountRate * aNumber)
            : aNumber;
    }
```

There's an assumption here that the discount rate is a positive number. I can make that assumption explicit by using an assertion. But I can't easily place an assertion into a ternary expression, so first I'll reformulate it as an if-then statement.

class Customer...

```
    applyDiscount(aNumber) {
        if (!this.discountRate) return aNumber;
        else return aNumber - (this.discountRate * aNumber);
    }
```

Now I can easily add the assertion.

class Customer...

```
    applyDiscount(aNumber) {
        if (!this.discountRate) return aNumber;
        else {
            assert(this.discountRate >= 0);
            return aNumber - (this.discountRate * aNumber);
        }
    }
```

In this case, I'd rather put this assertion into the setting method. If the assertion fails in `applyDiscount`, my first puzzle is how it got into the field in the first place.

class Customer...

```
set discountRate(aNumber) {  
    assert(null === aNumber || aNumber >= 0);  
    this._discountRate = aNumber;  
}
```

An assertion like this can be particularly valuable if it's hard to spot the error source—which may be an errant minus sign in some input data or some inversion elsewhere in the code.

There is a real danger of overusing assertions. I don't use assertions to check everything that I think is true, but only to check things that *need* to be true. Duplication is a particular problem, as it's common to tweak these kinds of conditions. So I find it's essential to remove any duplication in these conditions, usually by a liberal use of *Extract Function* (106).

I only use assertions for things that are programmer errors. If I'm reading data from an external source, any value checking should be a first-class part of the program, not an assertion—unless I'm really confident in the external source. Assertions are a last resort to help track bugs—though, ironically, I only use them when I think they should never fail.

Chapter 11

Refactoring APIs

Modules and their functions are the building blocks of our software. APIs are the joints that we use to plug them together. Making these APIs easy to understand and use is important but also difficult: I need to refactor them as I learn how to improve them.

A good API clearly separates any functions that update data from those that only read data. If I see them combined, I use *Separate Query from Modifier* (306) to tease them apart. I can unify functions that only vary due to a value with *Parameterize Function* (310). Some parameters, however, are really just a signal of an entirely different behavior and are best excised with *Remove Flag Argument* (314).

Data structures are often unpacked unnecessarily when passed between functions; I prefer to keep them together with *Preserve Whole Object* (319). Decisions on what should be passed as a parameter, and what can be resolved by the called function, are ones I often need to revisit with *Replace Parameter with Query* (324) and *Replace Query with Parameter* (327).

A class is a common form of module. I prefer my objects to be as immutable as possible, so I use *Remove Setting Method* (331) whenever I can. Often, when a caller asks for a new object, I need more flexibility than a simple constructor gives, which I can get by using *Replace Constructor with Factory Function* (334).

The last two refactorings address the difficulty of breaking down a particularly complex function that passes a lot of data around. I can turn that function into an object with *Replace Function with Command* (337), which makes it easier to use *Extract Function* (106) on the function's body. If I later simplify the function and no longer need it as a command object, I turn it back into a function with *Replace Command with Function* (344).

Separate Query from Modifier



```
function getTotalOutstandingAndSendBill() {  
  const result = customer.invoices.reduce((total, each) => each.amount + total, 0);  
  sendBill();  
  return result;  
}
```



```
function totalOutstanding() {  
  return customer.invoices.reduce((total, each) => each.amount + total, 0);  
}  
function sendBill() {  
  emailGateway.send(formatBill(customer));  
}
```

Motivation

When I have a function that gives me a value and has no observable side effects, I have a very valuable thing. I can call this function as often as I like. I can move the call to other places in a calling function. It's easier to test. In short, I have a lot less to worry about.

It is a good idea to clearly signal the difference between functions with side effects and those without. A good rule to follow is that any function that returns a value should not have observable side effects—the command-query separation [mf-cqs]. Some programmers treat this as an absolute rule. I'm not 100 percent pure on this (as on anything), but I try to follow it most of the time, and it has served me well.

If I come across a method that returns a value but also has side effects, I always try to separate the query from the modifier.

Note that I use the phrase *observable* side effects. A common optimization is to cache the value of a query in a field so that repeated calls go quicker. Although this changes the state of the object with the cache, the change is not observable. Any sequence of queries will always return the same results for each query.

Mechanics

- Copy the function, name it as a query.

Look into the function to see what is returned. If the query is used to populate a variable, the variable's name should provide a good clue.

- Remove any side effects from the new query function.
- Run static checks.
- Find each call of the original method. If that call uses the return value, replace the original call with a call to the query and insert a call to the original method below it. Test after each change.
- Remove return values from original.
- Test.

Often after doing this there will be duplication between the query and the original method that can be tidied up.

Example

Here is a function that scans a list of names for a miscreant. If it finds one, it returns the name of the bad guy and sets off the alarms. It only does this for the first miscreant it finds (I guess one is enough).

```
function alertForMiscreant (people) {
  for (const p of people) {
    if (p === "Don") {
      setOffAlarms();
      return "Don";
    }
    if (p === "John") {
      setOffAlarms();
      return "John";
    }
  }
  return "";
}
```

I begin by copying the function, naming it after the query aspect of the function.

```
function findMiscreant (people) {  
  for (const p of people) {  
    if (p === "Don") {  
      setOffAlarms();  
      return "Don";  
    }  
    if (p === "John") {  
      setOffAlarms();  
      return "John";  
    }  
  }  
  return "";  
}
```

I remove the side effects from this new query.

```
function findMiscreant (people) {  
  for (const p of people) {  
    if (p === "Don") {  
      setOffAlarms();  
      return "Don";  
    }  
    if (p === "John") {  
      setOffAlarms();  
      return "John";  
    }  
  }  
  return "";  
}
```

I now go to each caller and replace it with a call to the query, followed by a call to the modifier. So

```
const found = alertForMiscreant(people);
```

changes to

```
const found = findMiscreant(people);  
alertForMiscreant(people);
```

I now remove the return values from the modifier.

```
function alertForMiscreant (people) {  
  for (const p of people) {  
    if (p === "Don") {  
      setOffAlarms();  
      return;  
    }  
    if (p === "John") {  
      setOffAlarms();  
      return;  
    }  
  }  
  return;  
}
```

Now I have a lot of duplication between the original modifier and the new query, so I can use *Substitute Algorithm (195)* so that the modifier uses the query.

```
function alertForMiscreant (people) {  
  if (findMiscreant(people) !== "") setOffAlarms();  
}
```

Parameterize Function

formerly: *Parameterize Method*



```
function tenPercentRaise(aPerson) {  
  aPerson.salary = aPerson.salary.multiply(1.1);  
}  
function fivePercentRaise(aPerson) {  
  aPerson.salary = aPerson.salary.multiply(1.05);  
}
```



```
function raise(aPerson, factor) {  
  aPerson.salary = aPerson.salary.multiply(1 + factor);  
}
```

Motivation

If I see two functions that carry out very similar logic with different literal values, I can remove the duplication by using a single function with parameters for the different values. This increases the usefulness of the function, since I can apply it elsewhere with different values.

Mechanics

- Select one of the similar methods.
- Use *Change Function Declaration (124)* to add any literals that need to turn into parameters.
- For each caller of the function, add the literal value.
- Test.
- Change the body of the function to use the new parameters. Test after each change.
- For each similar function, replace the call with a call to the parameterized function. Test after each one.

If the original parameterized function doesn't work for a similar function, adjust it for the new function before moving on to the next.

Example

An obvious example is something like this:

```
function tenPercentRaise(aPerson) {
  aPerson.salary = aPerson.salary.multiply(1.1);
}
function fivePercentRaise(aPerson) {
  aPerson.salary = aPerson.salary.multiply(1.05);
}
```

Hopefully it's obvious that I can replace these with

```
function raise(aPerson, factor) {
  aPerson.salary = aPerson.salary.multiply(1 + factor);
}
```

But it can be a bit more involved than that. Consider this code:

```
function baseCharge(usage) {
  if (usage < 0) return usd(0);
  const amount =
    bottomBand(usage) * 0.03
    + middleBand(usage) * 0.05
    + topBand(usage) * 0.07;
  return usd(amount);
}

function bottomBand(usage) {
  return Math.min(usage, 100);
}

function middleBand(usage) {
  return usage > 100 ? Math.min(usage, 200) - 100 : 0;
}

function topBand(usage) {
  return usage > 200 ? usage - 200 : 0;
}
```

Here the logic is clearly pretty similar—but is it similar enough to support creating a parameterized method for the bands? It is, but may be a touch less obvious than the trivial case above.

When looking to parameterize some related functions, my approach is to take one of the functions and add parameters to it, with an eye to the other cases. With range-oriented things like this, usually the place to start is with the middle range. So I'll work on `middleBand` to change it to use parameters, and then adjust other callers to fit.

`middleBand` uses two literal values: 100 and 200. These represent the bottom and top of this middle band. I begin by using *Change Function Declaration (124)* to add them to the call. While I'm at it, I'll also change the name of the function to something that makes sense with the parameterization.

```
function withinBand(usage, bottom, top) {
  return usage > 100 ? Math.min(usage, 200) - 100 : 0;
}

function baseCharge(usage) {
  if (usage < 0) return usd(0);
  const amount =
    bottomBand(usage) * 0.03
    + withinBand(usage, 100, 200) * 0.05
    + topBand(usage) * 0.07;
  return usd(amount);
}
```

I replace each literal with a reference to the parameter:

```
function withinBand(usage, bottom, top) {
  return usage > bottom ? Math.min(usage, 200) - bottom : 0;
}
```

then:

```
function withinBand(usage, bottom, top) {
  return usage > bottom ? Math.min(usage, top) - bottom : 0;
}
```

I replace the call to the bottom band with a call to the newly parameterized function.

```
function baseCharge(usage) {
  if (usage < 0) return usd(0);
  const amount =
    withinBand(usage, 0, 100) * 0.03
    + withinBand(usage, 100, 200) * 0.05
    + topBand(usage) * 0.07;
  return usd(amount);
}

function bottomBand(usage) {
  return Math.min(usage, 100);
}
```

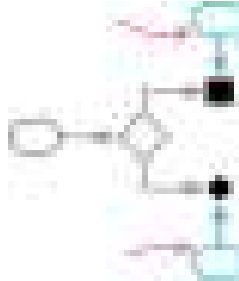
To replace the call to the top band, I need to make use of infinity.

```
function baseCharge(usage) {  
  if (usage < 0) return usd(0);  
  const amount =  
    withinBand(usage, 0, 100) * 0.03  
    + withinBand(usage, 100, 200) * 0.05  
    + withinBand(usage, 200, Infinity) * 0.07;  
  return usd(amount);  
}  
  
function topBand(usage) {  
  return usage > 200 ? usage - 200 : 0;  
}
```

With the logic working the way it does now, I could remove the initial guard clause. But although it's logically unnecessary now, I like to keep it as it documents how to handle that case.

Remove Flag Argument

formerly: *Replace Parameter with Explicit Methods*



```
function setDimension(name, value) {
  if (name === "height") {
    this._height = value;
    return;
  }
  if (name === "width") {
    this._width = value;
    return;
  }
}
```



```
function setHeight(value) {this._height = value;}
function setWidth (value) {this._width = value;}
```

Motivation

A flag argument is a function argument that the caller uses to indicate which logic the called function should execute. I may call a function that looks like this:

```
function bookConcert(aCustomer, isPremium) {
  if (isPremium) {
    // logic for premium booking
  } else {
    // logic for regular booking
  }
}
```


To book a premium concert, I issue the call like so:

```
bookConcert(aCustomer, true);
```

Flag arguments can also come as enums:

```
bookConcert(aCustomer, CustomerType.PREMIUM);
```

or strings (or symbols in languages that use them):

```
bookConcert(aCustomer, "premium");
```

I dislike flag arguments because they complicate the process of understanding what function calls are available and how to call them. My first route into an API is usually the list of available functions, and flag arguments hide the differences in the function calls that are available. Once I select a function, I have to figure out what values are available for the flag arguments. Boolean flags are even worse since they don't convey their meaning to the reader—in a function call, I can't figure out what `true` means. It's clearer to provide an explicit function for the task I want to do.

```
premiumBookConcert(aCustomer);
```

Not all arguments like this are flag arguments. To be a flag argument, the callers must be setting the boolean value to a literal value, not data that's flowing through the program. Also, the implementation function must be using the argument to influence its control flow, not as data that it passes to further functions.

Removing flag arguments doesn't just make the code clearer—it also helps my tooling. Code analysis tools can now more easily see the difference between calling the premium logic and calling regular logic.

Flag arguments can have a place if there's more than one of them in the function, since otherwise I would need explicit functions for every combination of their values. But that's also a signal of a function doing too much, and I should look for a way to create simpler functions that I can compose for this logic.

Mechanics

- Create an explicit function for each value of the parameter.

If the main function has a clear dispatch conditional, use *Decompose Conditional (260)* to create the explicit functions. Otherwise, create wrapping functions.

- For each caller that uses a literal value for the parameter, replace it with a call to the explicit function.

Example

Looking through some code, I see calls to calculate a delivery date for a shipment. Some of the calls look like

```
aShipment.deliveryDate = deliveryDate(anOrder, true);
```

and some look like

```
aShipment.deliveryDate = deliveryDate(anOrder, false);
```

Faced with code like this, I immediately begin to wonder about the meaning of the boolean value. What is it doing?

The body of `deliveryDate` looks like this:

```
function deliveryDate(anOrder, isRush) {  
  if (isRush) {  
    let deliveryTime;  
    if (["MA", "CT"].includes(anOrder.deliveryState)) deliveryTime = 1;  
    else if (["NY", "NH"].includes(anOrder.deliveryState)) deliveryTime = 2;  
    else deliveryTime = 3;  
    return anOrder.placedOn.plusDays(1 + deliveryTime);  
  }  
  else {  
    let deliveryTime;  
    if (["MA", "CT", "NY"].includes(anOrder.deliveryState)) deliveryTime = 2;  
    else if (["ME", "NH"].includes(anOrder.deliveryState)) deliveryTime = 3;  
    else deliveryTime = 4;  
    return anOrder.placedOn.plusDays(2 + deliveryTime);  
  }  
}
```

Here, the caller is using a literal boolean value to determine which code should run—a classic flag argument. But the whole point of using a function is to follow the caller's instructions, so it is better to clarify the caller's intent with explicit functions.

In this case, I can do this by using *Decompose Conditional (260)*, which gives me this:

```
function deliveryDate(anOrder, isRush) {  
  if (isRush) return rushDeliveryDate(anOrder);  
  else      return regularDeliveryDate(anOrder);  
}
```

```
function rushDeliveryDate(anOrder) {
  let deliveryTime;
  if (["MA", "CT"] .includes(anOrder.deliveryState)) deliveryTime = 1;
  else if (["NY", "NH"] .includes(anOrder.deliveryState)) deliveryTime = 2;
  else deliveryTime = 3;
  return anOrder.placedOn.plusDays(1 + deliveryTime);
}
function regularDeliveryDate(anOrder) {
  let deliveryTime;
  if (["MA", "CT", "NY"] .includes(anOrder.deliveryState)) deliveryTime = 2;
  else if (["ME", "NH"] .includes(anOrder.deliveryState)) deliveryTime = 3;
  else deliveryTime = 4;
  return anOrder.placedOn.plusDays(2 + deliveryTime);
}
```

The two new functions capture the intent of the call better, so I can replace each call of

```
aShipment.deliveryDate = deliveryDate(anOrder, true);
```

with

```
aShipment.deliveryDate = rushDeliveryDate(anOrder);
```

and similarly with the other case.

When I've replaced all the callers, I remove `deliveryDate`.

A flag argument isn't just the presence of a boolean value; it's that the boolean is set with a literal rather than data. If all the callers of `deliveryDate` were like this:

```
const isRush = determineIfRush(anOrder);
aShipment.deliveryDate = deliveryDate(anOrder, isRush);
```

then I'd have no problem with `deliveryDate`'s signature (although I'd still want to apply *Decompose Conditional* (260)).

It may be that some callers use the argument as a flag argument by setting it with a literal, while others set the argument with data. In this case, I'd still use Remove Flag Argument, but not change the data callers and not remove `deliveryDate` at the end. That way I support both interfaces for the different uses.

Decomposing the conditional like this is a good way to carry out this refactoring, but it only works if the dispatch on the parameter is the outer part of the function (or I can easily refactor it to make it so). It's also possible that the parameter is used in a much more tangled way, such as this alternative version of `deliveryDate`:

```
function deliveryDate(anOrder, isRush) {
  let result;
  let deliveryTime;
  if (anOrder.deliveryState === "MA" || anOrder.deliveryState === "CT")
    deliveryTime = isRush? 1 : 2;
  else if (anOrder.deliveryState === "NY" || anOrder.deliveryState === "NH") {
    deliveryTime = 2;
    if (anOrder.deliveryState === "NH" && !isRush)
      deliveryTime = 3;
  }
  else if (isRush)
    deliveryTime = 3;
  else if (anOrder.deliveryState === "ME")
    deliveryTime = 3;
  else
    deliveryTime = 4;
  result = anOrder.placedOn.plusDays(2 + deliveryTime);
  if (isRush) result = result.minusDays(1);
  return result;
}
```

In this case, teasing out `isRush` into a top-level dispatch conditional is likely more work than I fancy. So instead, I can layer functions over the `deliveryDate`:

```
function rushDeliveryDate (anOrder) {return deliveryDate(anOrder, true);}
function regularDeliveryDate(anOrder) {return deliveryDate(anOrder, false);}
```

These wrapping functions are essentially partial applications of `deliveryDate`, although they are defined in program text rather than by composition of functions.

I can then do the same replacement of callers that I did with the decomposed conditional earlier on. If there aren't any callers using the parameter as data, I like to restrict its visibility or rename it to a name that conveys that it shouldn't be used directly (e.g., `deliveryDateHelperOnly`).

Preserve Whole Object



```
const low = aRoom.daysTempRange.low;  
const high = aRoom.daysTempRange.high;  
if (aPlan.withinRange(low, high))
```



```
if (aPlan.withinRange(aRoom.daysTempRange))
```

Motivation

If I see code that derives a couple of values from a record and then passes these values into a function, I like to replace those values with the whole record itself, letting the function body derive the values it needs.

Passing the whole record handles change better should the called function need more data from the whole in the future—that change would not require me to alter the parameter list. It also reduces the size of the parameter list, which usually makes the function call easier to understand. If many functions are called with the parts, they often duplicate the logic that manipulates these parts—logic that can often be moved to the whole.

The main reason I wouldn't do this is if I don't want the called function to have a dependency on the whole—which typically occurs when they are in different modules.

Pulling several values from an object to do some logic on them alone is a smell (*Feature Envy* (77)), and usually a signal that this logic should be moved into the whole itself. Preserve Whole Object is particularly common after I've done *Introduce Parameter Object* (140), as I hunt down any occurrences of the original data clump to replace them with the new object.

If several bits of code only use the same subset of an object's features, then that may indicate a good opportunity for *Extract Class* (182).

One case that many people miss is when an object calls another object with several of its own data values. If I see this, I can replace those values with a self-reference (this in JavaScript).

Mechanics

- Create an empty function with the desired parameters.

Give the function an easily searchable name so it can be replaced at the end.

- Fill the body of the new function with a call to the old function, mapping from the new parameters to the old ones.
- Run static checks.
- Adjust each caller to use the new function, testing after each change.

This may mean that some code that derives the parameter isn't needed, so can fall to *Remove Dead Code* (237).

- Once all original callers have been changed, use *Inline Function* (115) on the original function.
- Change the name of the new function and all its callers.

Example

Consider a room monitoring system. It compares its daily temperature range with a range in a predefined heating plan.

caller...

```
const low = aRoom.daysTempRange.low;
const high = aRoom.daysTempRange.high;
if (!aPlan.withinRange(low, high))
    alerts.push("room temperature went outside range");
```

class HeatingPlan...

```
withinRange(bottom, top) {
    return (bottom >= this._temperatureRange.low) && (top <= this._temperatureRange.high);
}
```

Instead of unpacking the range information when I pass it in, I can pass in the whole range object.

I begin by stating the interface I want as an empty function.

class HeatingPlan...

```
xxNEWwithinRange(aNumberRange) {
}
```

Since I intend it to replace the existing `withinRange`, I name it the same but with an easily replaceable prefix.

I then add the body of the function, which relies on calling the existing `withinRange`. The body thus consists of a mapping from the new parameter to the existing ones.

class HeatingPlan...

```
xxNEWwithinRange(aNumberRange) {
  return this.withinRange(aNumberRange.low, aNumberRange.high);
}
```

Now I can begin the serious work, taking the existing function calls and having them call the new function.

caller...

```
const low = aRoom.daysTempRange.low;
const high = aRoom.daysTempRange.high;
if (!aPlan.xxNEWwithinRange(aRoom.daysTempRange))
  alerts.push("room temperature went outside range");
```

When I've changed the calls, I may see that some of the earlier code isn't needed anymore, so I wield *Remove Dead Code (237)*.

caller...

```
const low = aRoom.daysTempRange.low;
const high = aRoom.daysTempRange.high;
if (!aPlan.xxNEWwithinRange(aRoom.daysTempRange))
  alerts.push("room temperature went outside range");
```

I replace these one at a time, testing after each change.

Once I've replaced them all, I can use *Inline Function (115)* on the original function.

class HeatingPlan...

```
xxNEWwithinRange(aNumberRange) {
  return (aNumberRange.low >= this._temperatureRange.low) &&
    (aNumberRange.high <= this._temperatureRange.high);
}
```

And I finally remove that ugly prefix from the new function and all its callers. The prefix makes it a simple global replace, even if I don't have a robust rename support in my editor.

class HeatingPlan...

```
withinRange(aNumberRange) {
  return (aNumberRange.low >= this._temperatureRange.low) &&
    (aNumberRange.high <= this._temperatureRange.high);
}
```

caller...

```
if (!aPlan.withinRange(aRoom.daysTempRange))
  alerts.push("room temperature went outside range");
```

Example: A Variation to Create the New Function

In the above example, I wrote the code for the new function directly. Most of the time, that's pretty simple and the easiest way to go. But there is a variation on this that's occasionally useful—which can allow me to compose the new function entirely from refactorings.

I start with a caller of the existing function.

caller...

```
const low = aRoom.daysTempRange.low;
const high = aRoom.daysTempRange.high;
if (!aPlan.withinRange(low, high))
  alerts.push("room temperature went outside range");
```

I want to rearrange the code so I can create the new function by using *Extract Function (106)* on some existing code. The caller code isn't quite there yet, but I can get there by using *Extract Variable (119)* a few times. First, I disentangle the call to the old function from the conditional.

caller...

```
const low = aRoom.daysTempRange.low;
const high = aRoom.daysTempRange.high;
const isWithinRange = aPlan.withinRange(low, high);
if (!isWithinRange)
  alerts.push("room temperature went outside range");
```

I then extract the input parameter.

caller...

```
const tempRange = aRoom.daysTempRange;
const low = tempRange.low;
const high = tempRange.high;
const isWithinRange = aPlan.withinRange(low, high);
if (!isWithinRange)
  alerts.push("room temperature went outside range");
```

With that done, I can now use *Extract Function (106)* to create the new function.

caller...

```
const tempRange = aRoom.daysTempRange;
const isWithinRange = xxNEwwithinRange(aPlan, tempRange);
if (!isWithinRange)
  alerts.push("room temperature went outside range");
```


top level...

```
function xxNEWwithinRange(aPlan, tempRange) {  
  const low = tempRange.low;  
  const high = tempRange.high;  
  const isWithinRange = aPlan.withinRange(low, high);  
  return isWithinRange;  
}
```

Since the original function is in a different context (the `HeatingPlan` class), I need to use *Move Function (198)*.

caller...

```
const tempRange = aRoom.daysTempRange;  
const isWithinRange = aPlan.xxNEWwithinRange(tempRange);  
if (!isWithinRange)  
  alerts.push("room temperature went outside range");
```

class HeatingPlan...

```
xxNEWwithinRange(tempRange) {  
  const low = tempRange.low;  
  const high = tempRange.high;  
  const isWithinRange = this.withinRange(low, high);  
  return isWithinRange;  
}
```

I then continue as before, replacing other callers and inlining the old function into the new one. I would also inline the variables I extracted to provide the clean separation for extracting the new function.

Because this variation is entirely composed of refactorings, it's particularly handy when I have a refactoring tool with robust extract and inline operations.

Replace Parameter with Query

formerly: *Replace Parameter with Method*

inverse of: *Replace Query with Parameter* (327)



```
availableVacation(anEmployee, anEmployee.grade);  
  
function availableVacation(anEmployee, grade) {  
  // calculate vacation...
```



```
availableVacation(anEmployee)  
  
function availableVacation(anEmployee) {  
  const grade = anEmployee.grade;  
  // calculate vacation...
```

Motivation

The parameter list to a function should summarize the points of variability of that function, indicating the primary ways in which that function may behave differently. As with any statement in code, it's good to avoid any duplication, and it's easier to understand if the parameter list is short.

If a call passes in a value that the function can just as easily determine for itself, that's a form of duplication—one that unnecessarily complicates the caller which has to determine the value of a parameter when it could be freed from that work.

The limit on this is suggested by the phrase “just as easily.” By removing the parameter, I'm shifting the responsibility for determining the parameter value. When the parameter is present, determining its value is the caller's responsibility; otherwise, that responsibility shifts to the function body. My usual habit is to simplify life for callers, which implies moving responsibility to the function body—but only if that responsibility is appropriate there.

The most common reason to avoid Replace Parameter with Query is if removing the parameter adds an unwanted dependency to the function body—forcing it to access a program element that I'd rather it remained ignorant of. This may be a

new dependency, or an existing one that I'd like to remove. Usually this comes up where I'd need to add a problematic function call to the function body, or access something within a receiver object that I'd prefer to move out later.

The safest case for Replace Parameter with Query is when the value of the parameter I want to remove is determined merely by querying another parameter in the list. There's rarely any point in passing two parameters if one can be determined from the other.

One thing to watch out for is if the function I'm looking at has referential transparency—that is, if I can be sure that it will behave the same way whenever it's called with the same parameter values. Such functions are much easier to reason about and test, and I don't want to alter them to lose that property. So I wouldn't replace a parameter with an access to a mutable global variable.

Mechanics

- If necessary, use *Extract Function (106)* on the calculation of the parameter.
- Replace references to the parameter in the function body with references to the expression that yields the parameter. Test after each change.
- Use *Change Function Declaration (124)* to remove the parameter.

Example

I most often use Replace Parameter with Query when I've done some other refactorings that make a parameter no longer needed. Consider this code.

class Order...

```
get finalPrice() {
  const basePrice = this.quantity * this.itemPrice;
  let discountLevel;
  if (this.quantity > 100) discountLevel = 2;
  else discountLevel = 1;
  return this.discountedPrice(basePrice, discountLevel);
}

discountedPrice(basePrice, discountLevel) {
  switch (discountLevel) {
    case 1: return basePrice * 0.95;
    case 2: return basePrice * 0.9;
  }
}
```

When I'm simplifying a function, I'm keen to apply *Replace Temp with Query (178)*, which would lead me to

class Order...

```
get finalPrice() {  
  const basePrice = this.quantity * this.itemPrice;  
  return this.discountedPrice(basePrice, this.discountLevel);  
}  
  
get discountLevel() {  
  return (this.quantity > 100) ? 2 : 1;  
}
```

Once I've done this, there's no need to pass the result of `discountLevel` to `discountedPrice`—it can just as easily make the call itself.

I replace any reference to the parameter with a call to the method instead.

class Order...

```
discountedPrice(basePrice, discountLevel) {  
  switch (this.discountLevel) {  
    case 1: return basePrice * 0.95;  
    case 2: return basePrice * 0.9;  
  }  
}
```

I can then use *Change Function Declaration (124)* to remove the parameter.

class Order...

```
get finalPrice() {  
  const basePrice = this.quantity * this.itemPrice;  
  return this.discountedPrice(basePrice, this.discountLevel);  
}  
  
discountedPrice(basePrice, discountLevel) {  
  switch (this.discountLevel) {  
    case 1: return basePrice * 0.95;  
    case 2: return basePrice * 0.9;  
  }  
}
```

Replace Query with Parameter

inverse of: *Replace Parameter with Query* (324)



```
targetTemperature(aPlan)

function targetTemperature(aPlan) {
  currentTemperature = thermostat.currentTemperature;
  // rest of function...
```



```
targetTemperature(aPlan, thermostat.currentTemperature)

function targetTemperature(aPlan, currentTemperature) {
  // rest of function...
```

Motivation

When looking through a function's body, I sometimes see references to something in the function's scope that I'm not happy with. This might be a reference to a global variable, or to an element in the same module that I intend to move away. To resolve this, I need to replace the internal reference with a parameter, shifting the responsibility of resolving the reference to the caller of the function.

Most of these cases are due to my wish to alter the dependency relationships in the code—to make the target function no longer dependent on the element I want to parameterize. There's a tension here between converting everything to parameters, which results in long repetitive parameter lists, and sharing a lot of scope which can lead to a lot of coupling between functions. Like most tricky decisions, it's not something I can reliably get right, so it's important that I can reliably change things so the program can take advantage of my increasing understanding.

It's easier to reason about a function that will always give the same result when called with same parameter values—this is called referential transparency. If a function accesses some element in its scope that isn't referentially transparent, then the containing function also lacks referential transparency. I can fix that by

moving that element to a parameter. Although such a move will shift responsibility to the caller, there is often a lot to be gained by creating clear modules with referential transparency. A common pattern is to have modules consisting of pure functions which are wrapped by logic that handles the I/O and other variable elements of a program. I can use Replace Query with Parameter to purify parts of a program, making those parts easier to test and reason about.

But Replace Query with Parameter isn't just a bag of benefits. By moving a query to a parameter, I force my caller to figure out how to provide this value. This complicates life for callers of the functions, and my usual bias is to design interfaces that make life easier for their consumers. In the end, it boils down to allocation of responsibility around the program, and that's a decision that's neither easy nor immutable—which is why this refactoring (and its inverse) is one that I need to be very familiar with.

Mechanics

- Use *Extract Variable* (119) on the query code to separate it from the rest of the function body.
- Apply *Extract Function* (106) to the body code that isn't the call to the query.

Give the new function an easily searchable name, for later renaming.

- Use *Inline Variable* (123) to get rid of the variable you just created.
- Apply *Inline Function* (115) to the original function.
- Rename the new function to that of the original.

Example

Consider a simple, yet annoying, control system for temperature. It allows the user to select a temperature on a thermostat—but only sets the target temperature within a range determined by a heating plan.

class HeatingPlan...

```
get targetTemperature() {  
  if (thermostat.selectedTemperature > this._max) return this._max;  
  else if (thermostat.selectedTemperature < this._min) return this._min;  
  else return thermostat.selectedTemperature;  
}
```

caller...

```
if (thePlan.targetTemperature > thermostat.currentTemperature) setToHeat();  
else if (thePlan.targetTemperature < thermostat.currentTemperature) setToCool();  
else setOff();
```

As a user of such a system, I might be annoyed to have my desires overridden by the heating plan rules, but as a programmer I might be more concerned about how the `targetTemperature` function has a dependency on a global thermostat object. I can break this dependency by moving it to a parameter.

My first step is to use *Extract Variable (119)* on the parameter that I want to have in my function.

class HeatingPlan...

```
get targetTemperature() {
  const selectedTemperature = thermostat.selectedTemperature;
  if (selectedTemperature > this._max) return this._max;
  else if (selectedTemperature < this._min) return this._min;
  else return selectedTemperature;
}
```

That makes it easy to apply *Extract Function (106)* on the entire body of the function except for the bit that figures out the parameter.

class HeatingPlan...

```
get targetTemperature() {
  const selectedTemperature = thermostat.selectedTemperature;
  return this.xxNEWtargetTemperature(selectedTemperature);
}

xxNEWtargetTemperature(selectedTemperature) {
  if (selectedTemperature > this._max) return this._max;
  else if (selectedTemperature < this._min) return this._min;
  else return selectedTemperature;
}
```

I then inline the variable I just extracted, which leaves the function as a simple call.

class HeatingPlan...

```
get targetTemperature() {
  return this.xxNEWtargetTemperature(thermostat.selectedTemperature);
}
```

I can now use *Inline Function (115)* on this method.

caller...

```
if (thePlan.xxNEWtargetTemperature(thermostat.selectedTemperature) >
    thermostat.currentTemperature)
  setToHeat();
else if (thePlan.xxNEWtargetTemperature(thermostat.selectedTemperature) <
    thermostat.currentTemperature)
  setToCool();
else
  setOff();
```

I take advantage of the easily searchable name of the new function to rename it by removing the prefix.

caller...

```
if (thePlan.targetTemperature(thermostat.selectedTemperature) >
    thermostat.currentTemperature)
    setToHeat();
else if (thePlan.targetTemperature(thermostat.selectedTemperature) <
    thermostat.currentTemperature)
    setToCool();
else
    setOff();
```

class HeatingPlan...

```
targetTemperature(selectedTemperature) {
  if (selectedTemperature > this._max) return this._max;
  else if (selectedTemperature < this._min) return this._min;
  else return selectedTemperature;
}
```

As is often the case with this refactoring, the calling code looks more unwieldy than before. Moving a dependency out of a module pushes the responsibility of dealing with that dependency back to the caller. That's the trade-off for the reduced coupling.

But removing the coupling to the thermostat object isn't the only gain I've made with this refactoring. The `HeatingPlan` class is immutable—its fields are set in the constructor with no methods to alter them. (I'll save you the effort of looking at the whole class; just trust me on this.) Given an immutable heating plan, by moving the thermostat reference out of the function body I've also made `targetTemperature` referentially transparent. Every time I call `targetTemperature` on the same object, with the same argument, I will get the same result. If all the methods of the heating plan have referential transparency, that makes this class much easier to test and reason about.

A problem with JavaScript's class model is that it's impossible to enforce an immutable class—there's always a way to get at an object's data. But writing a class to signal and encourage immutability is often good enough. Creating classes that have this characteristic is often a sound strategy and `Replace Query with Parameter` is a handy tool for doing this.

Remove Setting Method



```
class Person {  
    get name() {...}  
    set name(aString) {...}
```



```
class Person {  
    get name() {...}
```

Motivation

Providing a setting method indicates that a field may be changed. If I don't want that field to change once the object is created, I don't provide a setting method (and make the field immutable). That way, the field is set only in the constructor, my intention to have it not change is clear, and I usually remove the very possibility that the field will change.

There's a couple of common cases where this comes up. One is where people always use accessor methods to manipulate a field, even within constructors. This leads to the only call to a setting method being from the constructor. I prefer to remove the setting method to make it clear that updates make no sense after construction.

Another case is where the object is created by clients using creation script rather than by a simple constructor call. Such a creation script starts with the constructor call followed by a sequence of setter method calls to create the new object. Once the script is finished, we don't expect the new object to change some (or even all) of its fields. The setters are only expected to be called during this initial creation. In this case, I'd get rid of them to make my intentions clearer.

Mechanics

- If the value that's being set isn't provided to the constructor, use *Change Function Declaration (124)* to add it. Add a call to the setting method within the constructor.

If you wish to remove several setting methods, add all their values to the constructor at once. This simplifies the later steps.

- Remove each call of a setting method outside of the constructor, using the new constructor value instead. Test after each one.

If you can't replace the call to the setter by creating a new object (because you are updating a shared reference object), abandon the refactoring.

- Use *Inline Function (115)* on the setting method. Make the field immutable if possible.
- Test.

Example

I have a simple person class.

class Person...

```
get name() {return this._name;}
set name(arg) {this._name = arg;}
get id() {return this._id;}
set id(arg) {this._id = arg;}
```

At the moment, I create a new object with code like this:

```
const martin = new Person();
martin.name = "martin";
martin.id = "1234";
```

The name of a person may change after it's created, but the ID does not. To make this clear, I want to remove the setting method for ID.

I still need to set the ID initially, so I'll use *Change Function Declaration (124)* to add it to the constructor.

class Person...

```
constructor(id) {
  this.id = id;
}
```

I then adjust the creation script to set the ID via the constructor.

```
const martin = new Person("1234");  
martin.name = "martin";  
martin.id = "1234";
```

I do this in each place I create a person, testing after each change.
When they are all done, I can apply *Inline Function (115)* to the setting method.

```
class Person...  
  constructor(id) {  
    this._id = id;  
  }  
  get name() {return this._name;}  
  set name(arg) {this._name = arg;}  
  get id() {return this._id;}  
set id(arg) {this._id = arg;}
```

Replace Constructor with Factory Function

formerly: *Replace Constructor with Factory Method*



```
leadEngineer = new Employee(document.leadEngineer, 'E');
```



```
leadEngineer = createEngineer(document.leadEngineer);
```

Motivation

Many object-oriented languages have a special constructor function that's called to initialize an object. Clients typically call this constructor when they want to create a new object. But these constructors often come with awkward limitations that aren't there for more general functions. A Java constructor must return an instance of the class it was called with, which means I can't replace it with a subclass or proxy depending on the environment or parameters. Constructor naming is fixed, which makes it impossible for me to use a name that is clearer than the default. Constructors often require a special operator to invoke ("new" in many languages) which makes them difficult to use in contexts that expect normal functions.

A factory function suffers from no such limitations. It will likely call the constructor as part of its implementation, but I can freely substitute something else.

Mechanics

- Create a factory function, its body being a call to the constructor.
- Replace each call to the constructor with a call to the factory function.
- Test after each change.
- Limit the constructor's visibility as much as possible.

Example

A quick but wearisome example uses kinds of employees. Consider an employee class:

class Employee...

```

    constructor (name, typeCode) {
        this._name = name;
        this._typeCode = typeCode;
    }
    get name() {return this._name;}
    get type() {
        return Employee.legalTypeCodes[this._typeCode];
    }
    static get legalTypeCodes() {
        return {"E": "Engineer", "M": "Manager", "S": "Salesman"};
    }

```

This is used from

caller...

```

    candidate = new Employee(document.name, document.empType);

```

and

caller...

```

    const leadEngineer = new Employee(document.leadEngineer, 'E');

```

My first step is to create the factory function. Its body is a simple delegation to the constructor.

top level...

```

    function createEmployee(name, typeCode) {
        return new Employee(name, typeCode);
    }

```

I then find the callers of the constructor and change them, one at a time, to use the factory function instead.

The first one is obvious:

caller...

```

    candidate = createEmployee(document.name, document.empType);

```

With the second case, I could use the new factory function like this:

caller...

```

    const leadEngineer = createEmployee(document.leadEngineer, 'E');

```

But I don't like using the type code here—it's generally a bad smell to pass a code as a literal string. So I prefer to create a new factory function that embeds the kind of employee I want into its name.

caller...

```
const leadEngineer = createEngineer(document.leadEngineer);
```

top level...

```
function createEngineer(name) {  
  return new Employee(name, 'E');  
}
```

Replace Function with Command

formerly: *Replace Method with Method Object*

inverse of: *Replace Command with Function* (344)



```
function score(candidate, medicalExam, scoringGuide) {  
  let result = 0;  
  let healthLevel = 0;  
  // long body code  
}
```



```
class Scorer {  
  constructor(candidate, medicalExam, scoringGuide) {  
    this._candidate = candidate;  
    this._medicalExam = medicalExam;  
    this._scoringGuide = scoringGuide;  
  }  
  
  execute() {  
    this._result = 0;  
    this._healthLevel = 0;  
    // long body code  
  }  
}
```

Motivation

Functions—either freestanding or attached to objects as methods—are one of the fundamental building blocks of programming. But there are times when it’s useful to encapsulate a function into its own object, which I refer to as a “command object” or simply a **command**. Such an object is mostly built around a single method, whose request and execution is the purpose of the object.

A command offers a greater flexibility for the control and expression of a function than the plain function mechanism. Commands can have complimentary operations, such as undo. I can provide methods to build up their parameters to

support a richer lifecycle. I can build in customizations using inheritance and hooks. If I'm working in a language with objects but without first-class functions, I can provide much of that capability by using commands instead. Similarly, I can use methods and fields to help break down a complex function, even in a language that lacks nested functions, and I can call those methods directly while testing and debugging.

All these are good reasons to use commands, and I need to be ready to refactor functions into commands when I need to. But we must not forget that this flexibility, as ever, comes at a price paid in complexity. So, given the choice between a first-class function and a command, I'll pick the function 95% of the time. I only use a command when I specifically need a facility that simpler approaches can't provide.

Like many words in software development, "command" is rather overloaded. In the context I'm using it here, it is an object that encapsulates a request, following the command pattern in Design Patterns [gof]. When I use "command" in this sense, I use "command object" to set the context, and "command" afterwards. The word "command" is also used in the command-query separation principle [mf-cqs], where a command is an object method that changes observable state. I've always tried to avoid using command in that sense, preferring "modifier" or "mutator."

Mechanics

- Create an empty class for the function. Name it based on the function.
- Use *Move Function (198)* to move the function to the empty class.

Keep the original function as a forwarding function until at least the end of the refactoring.

Follow any convention the language has for naming commands. If there is no convention, choose a generic name for the command's execute function, such as "execute" or "call".

- Consider making a field for each argument, and move these arguments to the constructor.

Example

The JavaScript language has many faults, but one of its great decisions was to make functions first-class entities. I thus don't have to go through all the hoops of creating commands for common tasks that I need to do in languages without this facility. But there are still times when a command is the right tool for the job.

One of these cases is breaking up a complex function so I can better understand and modify it. To really show the value of this refactoring, I need a long and

complicated function—but that would take too long to write, let alone for you to read. Instead, I'll go with a function that's short enough not to need it. This one scores points for an insurance application:

```
function score(candidate, medicalExam, scoringGuide) {
  let result = 0;
  let healthLevel = 0;
  let highMedicalRiskFlag = false;

  if (medicalExam.isSmoker) {
    healthLevel += 10;
    highMedicalRiskFlag = true;
  }
  let certificationGrade = "regular";
  if (scoringGuide.stateWithLowCertification(candidate.originState)) {
    certificationGrade = "low";
    result -= 5;
  }
  // lots more code like this
  result -= Math.max(healthLevel - 5, 0);
  return result;
}
```

I begin by creating an empty class and then *Move Function (198)* to move the function into it.

```
function score(candidate, medicalExam, scoringGuide) {
  return new Scorer().execute(candidate, medicalExam, scoringGuide);
}

class Scorer {
  execute (candidate, medicalExam, scoringGuide) {
    let result = 0;
    let healthLevel = 0;
    let highMedicalRiskFlag = false;

    if (medicalExam.isSmoker) {
      healthLevel += 10;
      highMedicalRiskFlag = true;
    }
    let certificationGrade = "regular";
    if (scoringGuide.stateWithLowCertification(candidate.originState)) {
      certificationGrade = "low";
      result -= 5;
    }
    // lots more code like this
    result -= Math.max(healthLevel - 5, 0);
    return result;
  }
}
```

Most of the time, I prefer to pass arguments to a command on the constructor and have the execute method take no parameters. While this matters less for a simple decomposition scenario like this, it's very handy when I want to manipulate the command with a more complicated parameter setting lifecycle or customizations. Different command classes can have different parameters but be mixed together when queued for execution.

I can do these parameters one at a time.

```
function score(candidate, medicalExam, scoringGuide) {
  return new Scorer(candidate).execute(candidate, medicalExam, scoringGuide);
}
```

class Scorer...

```
constructor(candidate){
  this._candidate = candidate;
}

execute (candidate, medicalExam, scoringGuide) {
  let result = 0;
  let healthLevel = 0;
  let highMedicalRiskFlag = false;

  if (medicalExam.isSmoker) {
    healthLevel += 10;
    highMedicalRiskFlag = true;
  }
  let certificationGrade = "regular";
  if (scoringGuide.stateWithLowCertification(this._candidate.originState)) {
    certificationGrade = "low";
    result -= 5;
  }
  // lots more code like this
  result -= Math.max(healthLevel - 5, 0);
  return result;
}
```

I continue with the other parameters

```
function score(candidate, medicalExam, scoringGuide) {
  return new Scorer(candidate, medicalExam, scoringGuide).execute();
}
```

class Scorer...

```
constructor(candidate, medicalExam, scoringGuide){
  this._candidate = candidate;
  this._medicalExam = medicalExam;
  this._scoringGuide = scoringGuide;
}
```

```

execute () {
  let result = 0;
  let healthLevel = 0;
  let highMedicalRiskFlag = false;

  if (this._medicalExam.isSmoker) {
    healthLevel += 10;
    highMedicalRiskFlag = true;
  }
  let certificationGrade = "regular";
  if (this._scoringGuide.stateWithLowCertification(this._candidate.originState)) {
    certificationGrade = "low";
    result -= 5;
  }
  // lots more code like this
  result -= Math.max(healthLevel - 5, 0);
  return result;
}

```

That completes Replace Function with Command, but the whole point of doing this refactoring is to allow me to break down the complicated functions—so let me outline some steps to achieve that. My next move here is to change all the local variables into fields. Again, I do these one at a time.

class Scorer...

```

constructor(candidate, medicalExam, scoringGuide){
  this._candidate = candidate;
  this._medicalExam = medicalExam;
  this._scoringGuide = scoringGuide;
}

execute () {
  this._result = 0;
  let healthLevel = 0;
  let highMedicalRiskFlag = false;

  if (this._medicalExam.isSmoker) {
    healthLevel += 10;
    highMedicalRiskFlag = true;
  }
  let certificationGrade = "regular";
  if (this._scoringGuide.stateWithLowCertification(this._candidate.originState)) {
    certificationGrade = "low";
    this._result -= 5;
  }
  // lots more code like this
  this._result -= Math.max(healthLevel - 5, 0);
  return this._result;
}

```

I repeat this for all the local variables. (This is one of those refactorings that I felt was sufficiently simple that I haven't given it an entry in the catalog. I feel slightly guilty about this.)

class Scorer...

```

constructor(candidate, medicalExam, scoringGuide){
  this._candidate = candidate;
  this._medicalExam = medicalExam;
  this._scoringGuide = scoringGuide;
}

execute () {
  this._result = 0;
  this._healthLevel = 0;
  this._highMedicalRiskFlag = false;

  if (this._medicalExam.isSmoker) {
    this._healthLevel += 10;
    this._highMedicalRiskFlag = true;
  }
  this._certificationGrade = "regular";
  if (this._scoringGuide.stateWithLowCertification(this._candidate.originState)) {
    this._certificationGrade = "low";
    this._result -= 5;
  }
  // lots more code like this
  this._result -= Math.max(this._healthLevel - 5, 0);
  return this._result;
}

```

Now I've moved all the function's state to the command object, I can use refactorings like *Extract Function (106)* without getting tangled up in all the variables and their scopes.

class Scorer...

```

execute () {
  this._result = 0;
  this._healthLevel = 0;
  this._highMedicalRiskFlag = false;

  this.scoreSmoking();
  this._certificationGrade = "regular";
  if (this._scoringGuide.stateWithLowCertification(this._candidate.originState)) {
    this._certificationGrade = "low";
    this._result -= 5;
  }
  // lots more code like this
  this._result -= Math.max(this._healthLevel - 5, 0);
  return this._result;
}

```

```
scoreSmoking() {  
  if (this._medicalExam.isSmoker) {  
    this._healthLevel += 10;  
    this._highMedicalRiskFlag = true;  
  }  
}
```

This allows me to treat the command similarly to how I'd deal with a nested function. Indeed, when doing this refactoring in JavaScript, using nested functions would be a reasonable alternative to using a command. I'd still use a command for this, partly because I'm more familiar with commands and partly because with a command I can write tests and debugging calls against the subfunctions.

Replace Command with Function

inverse of: *Replace Function with Command* (337)



```
class ChargeCalculator {
  constructor (customer, usage){
    this._customer = customer;
    this._usage = usage;
  }
  execute() {
    return this._customer.rate * this._usage;
  }
}
```



```
function charge(customer, usage) {
  return customer.rate * usage;
}
```

Motivation

Command objects provide a powerful mechanism for handling complex computations. They can easily be broken down into separate methods sharing common state through the fields; they can be invoked via different methods for different effects; they can have their data built up in stages. But that power comes at a cost. Most of the time, I just want to invoke a function and have it do its thing. If that's the case, and the function isn't too complex, then a command object is more trouble than its worth and should be turned into a regular function.

Mechanics

- Apply *Extract Function* (106) to the creation of the command and the call to the command's execution method.

This creates the new function that will replace the command in due course.

- For each method called by the command's execution method, apply *Inline Function (115)*.

If the supporting function returns a value, use *Extract Variable (119)* on the call first and then *Inline Function (115)*.

- Use *Change Function Declaration (124)* to put all the parameters of the constructor into the command's execution method instead.
- For each field, alter the references in the command's execution method to use the parameter instead. Test after each change.
- Inline the constructor call and command's execution method call into the caller (which is the replacement function).
- Test.
- Apply *Remove Dead Code (237)* to the command class.

Example

I'll begin with this small command object:

```
class ChargeCalculator {
  constructor (customer, usage, provider){
    this._customer = customer;
    this._usage = usage;
    this._provider = provider;
  }
  get baseCharge() {
    return this._customer.baseRate * this._usage;
  }
  get charge() {
    return this.baseCharge + this._provider.connectionCharge;
  }
}
```

It is used by code like this:

caller...

```
monthCharge = new ChargeCalculator(customer, usage, provider).charge;
```

The command class is small and simple enough to be better off as a function. I begin by using *Extract Function (106)* to wrap the class creation and invocation.

caller...

```
monthCharge = charge(customer, usage, provider);
```

top level...

```
function charge(customer, usage, provider) {
  return new ChargeCalculator(customer, usage, provider).charge;
}
```

I have to decide how to deal with any supporting functions, in this case `baseCharge`. My usual approach for a function that returns a value is to first *Extract Variable (119)* on that value.

class ChargeCalculator...

```
get baseCharge() {
  return this._customer.baseRate * this._usage;
}
get charge() {
  const baseCharge = this.baseCharge;
  return baseCharge + this._provider.connectionCharge;
}
```

Then, I use *Inline Function (115)* on the supporting function.

class ChargeCalculator...

```
get charge() {
  const baseCharge = this._customer.baseRate * this._usage;
  return baseCharge + this._provider.connectionCharge;
}
```

I now have all the processing in a single function, so my next step is to move the data passed to the constructor to the main method. I first use *Change Function Declaration (124)* to add all the constructor parameters to the charge method.

class ChargeCalculator...

```
constructor (customer, usage, provider){
  this._customer = customer;
  this._usage = usage;
  this._provider = provider;
}

charge(customer, usage, provider) {
  const baseCharge = this._customer.baseRate * this._usage;
  return baseCharge + this._provider.connectionCharge;
}
```

top level...

```
function charge(customer, usage, provider) {
  return new ChargeCalculator(customer, usage, provider)
    .charge(customer, usage, provider);
}
```

Now I can alter the body of `charge` to use the passed parameters instead. I can do this one at a time.


```
class ChargeCalculator...
  constructor (customer, usage, provider){
    this._customer = customer;
    this._usage = usage;
    this._provider = provider;
  }

  charge(customer, usage, provider) {
    const baseCharge = customer.baseRate * this._usage;
    return baseCharge + this._provider.connectionCharge;
  }
```

I don't have to remove the assignment to `this._customer` in the constructor, as it will just be ignored. But I prefer to do it since that will make a test fail if I miss changing a use of field to the parameter. (And if a test doesn't fail, I should consider adding a new test.)

I repeat this for the other parameters, ending up with

```
class ChargeCalculator...
  charge(customer, usage, provider) {
    const baseCharge = customer.baseRate * usage;
    return baseCharge + provider.connectionCharge;
  }
```

Once I've done all of these, I can inline into the top-level charge function. This is a special kind of *Inline Function (115)*, as it's inlining both the constructor and method call together.

top level...

```
function charge(customer, usage, provider) {
  const baseCharge = customer.baseRate * usage;
  return baseCharge + provider.connectionCharge;
}
```

The command class is now dead code, so I'll use *Remove Dead Code (237)* to give it an honorable burial.

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Chapter 12

Dealing with Inheritance

In this final chapter, I'll turn to one of the best known features of object-oriented programming: inheritance. Like any powerful mechanism, it is both very useful and easy to misuse, and it's often hard to see the misuse until it's in the rear-view mirror.

Often, features need to move up or down the inheritance hierarchy. Several refactorings deal with that: *Pull Up Method* (350), *Pull Up Field* (353), *Pull Up Constructor Body* (355), *Push Down Method* (359), and *Push Down Field* (361). I can add and remove classes from the hierarchy with *Extract Superclass* (375), *Remove Subclass* (369), and *Collapse Hierarchy* (380). I may want to add a subclass to replace a field that I'm using to trigger different behavior based on its value; I do this with *Replace Type Code with Subclasses* (362).

Inheritance is a powerful tool, but sometimes it gets used in the wrong place—or the place it's used in becomes wrong. In that case, I use *Replace Subclass with Delegate* (381) or *Replace Superclass with Delegate* (399) to turn inheritance into delegation.

Pull Up Method

inverse of: *Push Down Method* (359)



```
class Employee {...}

class Salesman extends Employee {
    get name() {...}
}

class Engineer extends Employee {
    get name() {...}
}
```



```
class Employee {
    get name() {...}
}

class Salesman extends Employee {...}
class Engineer extends Employee {...}
```

Motivation

Eliminating duplicate code is important. Two duplicate methods may work fine as they are, but they are nothing but a breeding ground for bugs in the future. Whenever there is duplication, there is risk that an alteration to one copy will not be made to the other. Usually, it is difficult to find the duplicates.

The easiest case of using Pull Up Method is when the methods have the same body, implying there's been a copy and paste. Of course it's not always as obvious as that. I could just do the refactoring and see if the tests croak—but that puts a lot of reliance on my tests. I usually find it valuable to look for the differences—often, they show up behavior that I forgot to test for.

Often, Pull Up Method comes after other steps. I see two methods in different classes that can be parameterized in such a way that they end up as essentially the same method. In that case, the smallest step is for me to apply *Parameterize Function* (310) separately and then Pull Up Method.

The most awkward complication with Pull Up Method is if the body of the method refers to features that are on the subclass but not on the superclass. When that happens, I need to use *Pull Up Field* (353) and Pull Up Method on those elements first.

If I have two methods with a similar overall flow, but differing in details, I'll consider the Form Template Method [mf-ft].

Mechanics

- Inspect methods to ensure they are identical.

If they do the same thing, but are not identical, refactor them until they have identical bodies.

- Check that all method calls and field references inside the method body refer to features that can be called from the superclass.
- If the methods have different signatures, use *Change Function Declaration* (124) to get them to the one you want to use on the superclass.
- Create a new method in the superclass. Copy the body of one of the methods over to it.
- Run static checks.
- Delete one subclass method.
- Test.
- Keep deleting subclass methods until they are all gone.

Example

I have two subclass methods that do the same thing.

```
class Employee extends Party...
```

```
    get annualCost() {  
        return this.monthlyCost * 12;  
    }
```

```
class Department extends Party...
```

```
    get totalAnnualCost() {  
        return this.monthlyCost * 12;  
    }
```

I look at both classes and see that they refer to the `monthlyCost` property which isn't defined on the superclass, but is present in both subclasses. Since I'm in a dynamic language, I'm OK; if I were in a static language, I'd need to define an abstract method on `Party`.

The methods have different names, so I *Change Function Declaration (124)* to make them the same.

class Department...

```
get annualCost() {  
  return this.monthlyCost * 12;  
}
```

I copy the method from one subclass and paste it into the superclass.

class Party...

```
get annualCost() {  
  return this.monthlyCost * 12;  
}
```

In a static language, I'd compile to ensure that all the references were OK. That won't help me here, so I first remove `annualCost` from `Employee`, test, and then remove it from `Department`.

That completes the refactoring, but does leave a question. `annualCost` calls `monthlyCost`, but `monthlyCost` doesn't appear in the `Party` class. It all works, because JavaScript is a dynamic language—but there is value in signaling that subclasses of `Party` should provide an implementation for `monthlyCost`, particularly if more subclasses get added later on. A good way to provide this signal is a trap method like this:

class Party...

```
get monthlyCost() {  
  throw new SubclassResponsibilityError();  
}
```

I call such an error a subclass responsibility error as that was the name used in `Smalltalk`.

Pull Up Field

inverse of: *Push Down Field* (361)



```
class Employee {...} // Java

class Salesman extends Employee {
    private String name;
}

class Engineer extends Employee {
    private String name;
}
```



```
class Employee {
    protected String name;
}

class Salesman extends Employee {...}
class Engineer extends Employee {...}
```

Motivation

If subclasses are developed independently, or combined through refactoring, I often find that they duplicate features. In particular, certain fields can be duplicates. Such fields sometimes have similar names—but not always. The only way I can tell what is going on is by looking at the fields and examining how they are used. If they are being used in a similar way, I can pull them up into the superclass.

By doing this, I reduce duplication in two ways. I remove the duplicate data declaration and I can then move behavior that uses the field from the subclasses to the superclass.

Many dynamic languages do not define fields as part of their class definition—instead, fields appear when they are first assigned to. In this case, pulling up a field is essentially a consequence of *Pull Up Constructor Body* (355).

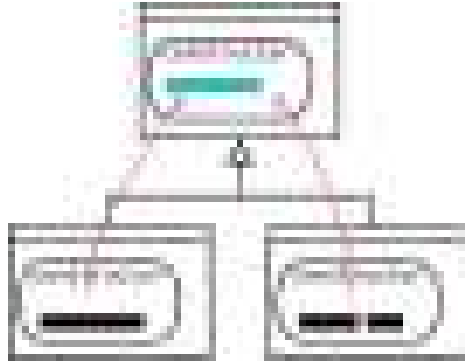
Mechanics

- Inspect all users of the candidate field to ensure they are used in the same way.
- If the fields have different names, use *Rename Field* (244) to give them the same name.
- Create a new field in the superclass.

The new field will need to be accessible to subclasses (protected in common languages).

- Delete the subclass fields.
- Test.

Pull Up Constructor Body



```
class Party {...}

class Employee extends Party {
  constructor(name, id, monthlyCost) {
    super();
    this._id = id;
    this._name = name;
    this._monthlyCost = monthlyCost;
  }
}
```



```
class Party {
  constructor(name){
    this._name = name;
  }
}

class Employee extends Party {
  constructor(name, id, monthlyCost) {
    super(name);
    this._id = id;
    this._monthlyCost = monthlyCost;
  }
}
```

Motivation

Constructors are tricky things. They aren't quite normal methods—so I'm more restricted in what I can do with them.

If I see subclass methods with common behavior, my first thought is to use *Extract Function* (106) followed by *Pull Up Method* (350), which will move it nicely into the superclass. Constructors tangle that—because they have special rules about what can be done in what order, so I need a slightly different approach.

If this refactoring starts getting messy, I reach for *Replace Constructor with Factory Function* (334).

Mechanics

- Define a superclass constructor, if one doesn't already exist. Ensure it's called by subclass constructors.
- Use *Slide Statements* (223) to move any common statements to just after the super call.
- Remove the common code from each subclass and put it in the superclass. Add to the super call any constructor parameters referenced in the common code.
- Test.
- If there is any common code that cannot move to the start of the constructor, use *Extract Function* (106) followed by *Pull Up Method* (350).

Example

I start with the following code:

```
class Party {}

class Employee extends Party {
  constructor(name, id, monthlyCost) {
    super();
    this._id = id;
    this._name = name;
    this._monthlyCost = monthlyCost;
  }
  // rest of class...
```

```
class Department extends Party {
  constructor(name, staff){
    super();
    this._name = name;
    this._staff = staff;
  }
  // rest of class...
```

The common code here is the assignment of the name. I use *Slide Statements (223)* to move the assignment in `Employee` next to the call to `super()`:

```
class Employee extends Party {
  constructor(name, id, monthlyCost) {
    super();
    this._name = name;
    this._id = id;
    this._monthlyCost = monthlyCost;
  }
  // rest of class...
```

With that tested, I move the common code to the superclass. Since that code contains a reference to a constructor argument, I pass that in as a parameter.

class Party...

```
constructor(name){
  this._name = name;
}
```

class Employee...

```
constructor(name, id, monthlyCost) {
  super(name);
  this._id = id;
  this._monthlyCost = monthlyCost;
}
```

class Department...

```
constructor(name, staff){
  super(name);
  this._staff = staff;
}
```

Run the tests, and I'm done.

Most of the time, constructor behavior will work like this: Do the common elements first (with a `super` call), then do extra work that the subclass needs. Occasionally, however, there is some common behavior later.

Consider this example:

class Employee...

```
    constructor (name) {...}

    get isPrivileged() {...}

    assignCar() {...}
```

class Manager extends Employee...

```
    constructor(name, grade) {
        super(name);
        this._grade = grade;
        if (this.isPrivileged) this.assignCar(); // every subclass does this
    }

    get isPrivileged() {
        return this._grade > 4;
    }
```

The wrinkle here comes from the fact that the call to `isPrivileged` can't be made until after the `grade` field is assigned, and that can only be done in the subclass.

In this case, I do *Extract Function (106)* on the common code:

class Manager...

```
    constructor(name, grade) {
        super(name);
        this._grade = grade;
        this.finishConstruction();
    }

    finishConstruction() {
        if (this.isPrivileged) this.assignCar();
    }
```

Then, I use *Pull Up Method (350)* to move it to the superclass.

class Employee...

```
    finishConstruction() {
        if (this.isPrivileged) this.assignCar();
    }
```

Push Down Method

inverse of: *Pull Up Method* (350)



```
class Employee {  
    get quota {...}  
}  
  
class Engineer extends Employee {...}  
class Salesman extends Employee {...}
```



```
class Employee {...}  
class Engineer extends Employee {...}  
class Salesman extends Employee {  
    get quota {...}  
}
```

Motivation

If a method is only relevant to one subclass (or a small proportion of subclasses), removing it from the superclass and putting it only on the subclass(es) makes that clearer. I can only do this refactoring if the caller knows it's working with a particular subclass—otherwise, I should use *Replace Conditional with Polymorphism* (272) with some placebo behavior on the superclass.

Mechanics

- Copy the method into every subclass that needs it.
- Remove the method from the superclass.

- Test.
- Remove the method from each superclass that doesn't need it.
- Test.

Push Down Field

inverse of: *Pull Up Field* (353)



```
class Employee {      // Java
    private String quota;
}

class Engineer extends Employee {...}
class Salesman extends Employee {...}
```



```
class Employee {...}
class Engineer extends Employee {...}

class Salesman extends Employee {
    protected String quota;
}
```

Motivation

If a field is only used by one subclass (or a small proportion of subclasses), I move it to those subclasses.

Mechanics

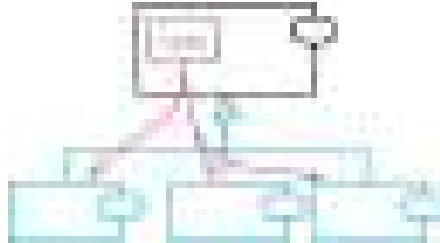
- Declare field in all subclasses that need it.
- Remove the field from the superclass.
- Test.
- Remove the field from all subclasses that don't need it.
- Test.

Replace Type Code with Subclasses

subsumes: *Replace Type Code with State/Strategy*

subsumes: *Extract Subclass*

inverse of: *Remove Subclass* (369)



```
function createEmployee(name, type) {
  return new Employee(name, type);
}
```



```
function createEmployee(name, type) {
  switch (type) {
    case "engineer": return new Engineer(name);
    case "salesman": return new Salesman(name);
    case "manager": return new Manager (name);
  }
}
```

Motivation

Software systems often need to represent different kinds of a similar thing. I may classify employees by their job type (engineer, manager, salesman), or orders by their priority (rush, regular). My first tool for handling this is some kind of type code field—depending on the language, that might be an enum, symbol, string, or number. Often, this type code will come from an external service that provides me with the data I'm working on.

Most of the time, such a type code is all I need. But there are a couple of situations where I could do with something more, and that something more are subclasses. There are two things that are particularly enticing about subclasses. First, they allow me to use polymorphism to handle conditional logic. I find this

most helpful when I have several functions that invoke different behavior depending on the value of the type code. With subclasses, I can apply *Replace Conditional with Polymorphism* (272) to these functions.

The second case is where I have fields or methods that are only valid for particular values of a type code, such as a sales quota that's only applicable to the "salesman" type code. I can then create the subclass and apply *Push Down Field* (361). While I can include validation logic to ensure a field is only used when the type code has the correct value, using a subclass makes the relationship more explicit.

When using Replace Type Code with Subclasses, I need to consider whether to apply it directly to the class I'm looking at, or to the type code itself. Do I make engineer a subtype of employee, or should I give the employee an employee type property which can have subtypes for engineer and manager? Using direct subclassing is simpler, but I can't use it for the job type if I need it for something else. I also can't use direct subclasses if the type is mutable. If I need to move the subclasses to an employee type property, I can do that by using *Replace Primitive with Object* (174) on the type code to create an employee type class and then using Replace Type Code with Subclasses on that new class.

Mechanics

- Self-encapsulate the type code field.
- Pick one type code value. Create a subclass for that type code. Override the type code getter to return the literal type code value.
- Create selector logic to map from the type code parameter to the new subclass.

With direct inheritance, use *Replace Constructor with Factory Function* (334) and put the selector logic in the factory. With indirect inheritance, the selector logic may stay in the constructor.

- Test.
- Repeat creating the subclass and adding to the selector logic for each type code value. Test after each change.
- Remove the type code field.
- Test.
- Use *Push Down Method* (359) and *Replace Conditional with Polymorphism* (272) on any methods that use the type code accessors. Once all are replaced, you can remove the type code accessors.

Example

I'll start with this overused employee example:

```
class Employee...
  constructor(name, type){
    this.validateType(type);
    this._name = name;
    this._type = type;
  }
  validateType(arg) {
    if (!["engineer", "manager", "salesman"].includes(arg))
      throw new Error(`Employee cannot be of type ${arg}`);
  }
  toString() {return `${this._name} (${this._type})`};
```

My first step is to use *Encapsulate Variable (132)* to self-encapsulate the type code.

```
class Employee...
  get type() {return this._type;}
  toString() {return `${this._name} (${this.type})`};
```

Note that toString uses the new getter by removing the underscore.

I pick one type code, the engineer, to start with. I use direct inheritance, subclassing the employee class itself. The employee subclass is simple—just overriding the type code getter with the appropriate literal value.

```
class Engineer extends Employee {
  get type() {return "engineer";}
}
```

Although JavaScript constructors can return other objects, things will get messy if I try to put selector logic in there, since that logic gets intertwined with field initialization. So I use *Replace Constructor with Factory Function (334)* to create a new space for it.

```
function createEmployee(name, type) {
  return new Employee(name, type);
}
```

To use the new subclass, I add selector logic into the factory.

```
function createEmployee(name, type) {
  switch (type) {
    case "engineer": return new Engineer(name, type);
  }
  return new Employee(name, type);
}
```

I test to ensure that worked out correctly. But, because I'm paranoid, I then alter the return value of the engineer's override and test again to ensure the test fails. That way I know the subclass is being used. I correct the return value and continue with the other cases. I can do them one at a time, testing after each change.

```
class Salesman extends Employee {
  get type() {return "salesman";}
}

class Manager extends Employee {
  get type() {return "manager";}
}

function createEmployee(name, type) {
  switch (type) {
    case "engineer": return new Engineer(name, type);
    case "salesman": return new Salesman(name, type);
    case "manager":  return new Manager (name, type);
  }
  return new Employee(name, type);
}
```

Once I'm done with them all, I can remove the type code field and the superclass getting method (the ones in the subclasses remain).

```
class Employee...
  constructor(name, type){
    this.validateType(type);
    this._name = name;
    this._type = type;
  }

  get type() {return this._type;}
  toString() {return `${this._name} (${this.type})`};}
```

After testing to ensure all is still well, I can remove the validation logic, since the switch is effectively doing the same thing.

```
class Employee...
  constructor(name, type){
    this.validateType(type);
    this._name = name;
  }
```

```
function createEmployee(name, type) {
  switch (type) {
    case "engineer": return new Engineer(name, type);
    case "salesman": return new Salesman(name, type);
    case "manager": return new Manager (name, type);
    default: throw new Error('Employee cannot be of type ${type}');
  }
  return new Employee(name, type);
}
```

The type argument to the constructor is now useless, so it falls victim to *Change Function Declaration (124)*.

class Employee...

```
constructor(name, type){
  this._name = name;
}

function createEmployee(name, type) {
  switch (type) {
    case "engineer": return new Engineer(name, type);
    case "salesman": return new Salesman(name, type);
    case "manager": return new Manager (name, type);
    default: throw new Error('Employee cannot be of type ${type}');
  }
}
```

I still have the type code accessors on the subclasses—get type. I'll usually want to remove these too, but that may take a bit of time due to other methods that depend on them. I'll use *Replace Conditional with Polymorphism (272)* and *Push Down Method (359)* to deal with these. At some point, I'll have no code that uses the type getters, so I will subject them to the tender mercies of *Remove Dead Code (237)*.

Example: Using Indirect Inheritance

Let's go back to the starting case—but this time, I already have existing subclasses for part-time and full-time employees, so I can't subclass from Employee for the type codes. Another reason to not use direct inheritance is keeping the ability to change the type of employee.

class Employee...

```

    constructor(name, type){
        this.validateType(type);
        this._name = name;
        this._type = type;
    }
    validateType(arg) {
        if (!["engineer", "manager", "salesman"].includes(arg))
            throw new Error(`Employee cannot be of type ${arg}`);
    }
    get type() {return this._type;}
    set type(arg) {this._type = arg;}

    get capitalizedType() {
        return this._type.charAt(0).toUpperCase() + this._type.substr(1).toLowerCase();
    }
    toString() {
        return `${this._name} (${this.capitalizedType})`;
    }

```

This time `toString` is a bit more complicated, to allow me to illustrate something shortly.

My first step is to use *Replace Primitive with Object (174)* on the type code.

```

class EmployeeType {
    constructor(aString) {
        this._value = aString;
    }
    toString() {return this._value;}
}

```

class Employee...

```

    constructor(name, type){
        this.validateType(type);
        this._name = name;
        this.type = type;
    }
    validateType(arg) {
        if (!["engineer", "manager", "salesman"].includes(arg))
            throw new Error(`Employee cannot be of type ${arg}`);
    }
    get typeString() {return this._type.toString();}
    get type() {return this._type;}
    set type(arg) {this._type = new EmployeeType(arg);}

    get capitalizedType() {
        return this.typeString.charAt(0).toUpperCase()
            + this.typeString.substr(1).toLowerCase();
    }

```

```
toString() {
    return `${this._name} (${this.capitalizedType})`;
}
```

I then apply the usual mechanics of Replace Type Code with Subclasses to the employee type.

class Employee...

```
set type(arg) {this._type = Employee.createEmployeeType(arg);}

static createEmployeeType(aString) {
    switch(aString) {
        case "engineer": return new Engineer();
        case "manager":  return new Manager ();
        case "salesman": return new Salesman();
        default: throw new Error(`Employee cannot be of type ${aString}`);
    }
}

class EmployeeType {
}
class Engineer extends EmployeeType {
    toString() {return "engineer";}
}
class Manager extends EmployeeType {
    toString() {return "manager";}
}
class Salesman extends EmployeeType {
    toString() {return "salesman";}
}
```

If I were leaving it at that, I could remove the empty `EmployeeType`. But I prefer to leave it there as it makes explicit the relationship between the various subclasses. It's also a handy spot for moving other behavior there, such as the capitalization logic I tossed into the example specifically to illustrate this point.

class Employee...

```
toString() {
    return `${this._name} (${this.type.capitalizedName})`;
}
```

class EmployeeType...

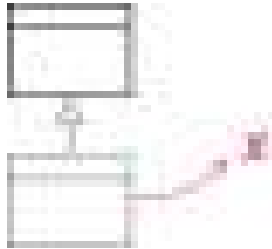
```
get capitalizedName() {
    return this.toString().charAt(0).toUpperCase()
        + this.toString().substr(1).toLowerCase();
}
```

For those familiar with the first edition of the book, this example essentially supersedes the Replace Type Code with State/Strategy. I now think of that refactoring as Replace Type Code with Subclasses using indirect inheritance, so didn't consider it worth its own entry in the catalog. (I never liked the name anyway.)

Remove Subclass

formerly: *Replace Subclass with Fields*

inverse of: *Replace Type Code with Subclasses* (362)



```
class Person {
    get genderCode() {return "X";}
}
class Male extends Person {
    get genderCode() {return "M";}
}
class Female extends Person {
    get genderCode() {return "F";}
}
```



```
class Person {
    get genderCode() {return this._genderCode;}
}
```

Motivation

Subclasses are useful. They support variations in data structure and polymorphic behavior. They are a good way to program by difference. But as a software system evolves, subclasses can lose their value as the variations they support are moved to other places or removed altogether. Sometimes, subclasses are added in anticipation of features that never end up being built, or end up being built in a way that doesn't need the subclasses.

A subclass that does too little incurs a cost in understanding that is no longer worthwhile. When that time comes, it's best to remove the subclass, replacing it with a field on its superclass.

Mechanics

- Use *Replace Constructor with Factory Function* (334) on the subclass constructor.

If the clients of the constructors use a data field to decide which subclass to create, put that decision logic into a superclass factory method.

- If any code tests against the subclass's types, use *Extract Function* (106) on the type test and *Move Function* (198) to move it to the superclass. Test after each change.
- Create a field to represent the subclass type.
- Change the methods that refer to the subclass to use the new type field.
- Delete the subclass.
- Test.

Often, this refactoring is used on a group of subclasses at once—in which case carry out the steps to encapsulate them (add factory function, move type tests) first, then individually fold them into the superclass.

Example

I'll start with this stump of subclasses:

```
class Person...
    constructor(name) {
        this._name = name;
    }
    get name() {return this._name;}
    get genderCode() {return "X";}
    // snip

    class Male extends Person {
        get genderCode() {return "M";}
    }

    class Female extends Person {
        get genderCode() {return "F";}
    }
```

If that's all that a subclass does, it's not really worth having. But before I remove these subclasses, it's usually worth checking to see if there's any subclass-dependent behavior in the clients that should be moved in there. In this case, I don't find anything worth keeping the subclasses for.

client...

```
const numberOfMales = people.filter(p => p instanceof Male).length;
```

Whenever I want to change how I represent something, I try to first encapsulate the current representation to minimize the impact on any client code. When it comes to creating subclasses, the way to encapsulate is to use *Replace Constructor with Factory Function (334)*. In this case, there's a couple of ways I could make the factory.

The most direct way is to create a factory method for each constructor.

```
function createPerson(name) {
  return new Person(name);
}
function createMale(name) {
  return new Male(name);
}
function createFemale(name) {
  return new Female(name);
}
```

But although that's the direct choice, objects like this are often loaded from a source that uses the gender codes directly.

```
function loadFromInput(data) {
  const result = [];
  data.forEach(aRecord => {
    let p;
    switch (aRecord.gender) {
      case 'M': p = new Male(aRecord.name); break;
      case 'F': p = new Female(aRecord.name); break;
      default: p = new Person(aRecord.name);
    }
    result.push(p);
  });
  return result;
}
```

In that case, I find it better to use *Extract Function (106)* on the selection logic for which class to create, and make that the factory function.

```
function createPerson(aRecord) {
  let p;
  switch (aRecord.gender) {
    case 'M': p = new Male(aRecord.name); break;
    case 'F': p = new Female(aRecord.name); break;
    default: p = new Person(aRecord.name);
  }
  return p;
}
```

```
function loadFromInput(data) {
  const result = [];
  data.forEach(aRecord => {
    result.push(createPerson(aRecord));
  });
  return result;
}
```

While I'm there, I'll clean up those two functions. I'll use *Inline Variable (123)* on `createPerson`:

```
function createPerson(aRecord) {
  switch (aRecord.gender) {
    case 'M': return new Male (aRecord.name);
    case 'F': return new Female(aRecord.name);
    default: return new Person(aRecord.name);
  }
}
```

and *Replace Loop with Pipeline (231)* on `loadFromInput`:

```
function loadFromInput(data) {
  return data.map(aRecord => createPerson(aRecord));
}
```

The factory encapsulates the creation of the subclasses, but there is also the use of `instanceof`—which never smells good. I use *Extract Function (106)* on the type check.

client...

```
const numberOfMales = people.filter(p => isMale(p)).length;

function isMale(aPerson) {return aPerson instanceof Male;}
```

Then I use *Move Function (198)* to move it into `Person`.

class Person...

```
  get isMale() {return this instanceof Male;}
```

client...

```
const numberOfMales = people.filter(p => p.isMale).length;
```

With that refactoring done, all knowledge of the subclasses is now safely encapsulated within the superclass and the factory function. (Usually I'm wary of a superclass referring to a subclass, but this code isn't going to last until my next cup of tea, so I'm not going to worry about it.)

I now add a field to represent the difference between the subclasses; since I'm using a code loaded from elsewhere, I might as well just use that.

class Person...

```

constructor(name, genderCode) {
  this._name = name;
  this._genderCode = genderCode || "X";
}

get genderCode() {return this._genderCode;}

```

When initializing it, I set it to the default case. (As a side note, although most people can be classified as male or female, there are people who can't. It's a common modeling mistake to forget that.)

I then take the male case and fold its logic into the superclass. This involves modifying the factory to return a Person and modifying any instanceof tests to use the gender code field.

```

function createPerson(aRecord) {
  switch (aRecord.gender) {
    case 'M': return new Person(aRecord.name, "M");
    case 'F': return new Female(aRecord.name);
    default: return new Person(aRecord.name);
  }
}

```

class Person...

```

get isMale() {return "M" === this._genderCode;}

```

I test, remove the male subclass, test again, and repeat for the female subclass.

```

function createPerson(aRecord) {
  switch (aRecord.gender) {
    case 'M': return new Person(aRecord.name, "M");
    case 'F': return new Person(aRecord.name, "F");
    default: return new Person(aRecord.name);
  }
}

```

I find the lack of symmetry with the gender code to be annoying. A future reader of the code will always wonder about this lack of symmetry. So I prefer to change the code to make it symmetrical—if I can do it without introducing any other complexity, which is the case here.

```

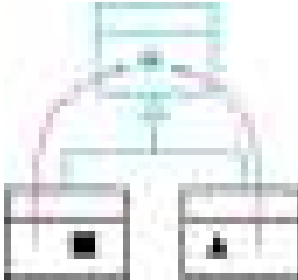
function createPerson(aRecord) {
  switch (aRecord.gender) {
    case 'M': return new Person(aRecord.name, "M");
    case 'F': return new Person(aRecord.name, "F");
    default: return new Person(aRecord.name, "X");
  }
}

```

class Person...

```
    constructor(name, genderCode) {  
        this._name = name;  
        this._genderCode = genderCode + "X";  
    }
```

Extract Superclass



```
class Department {
  get totalAnnualCost() {...}
  get name() {...}
  get headCount() {...}
}
```

```
class Employee {
  get annualCost() {...}
  get name() {...}
  get id() {...}
}
```



```
class Party {
  get name() {...}
  get annualCost() {...}
}
```

```
class Department extends Party {
  get annualCost() {...}
  get headCount() {...}
}
```

```
class Employee extends Party {
  get annualCost() {...}
  get id() {...}
}
```

Motivation

If I see two classes doing similar things, I can take advantage of the basic mechanism of inheritance to pull their similarities together into a superclass. I can use *Pull Up Field* (353) to move common data into the superclass, and *Pull Up Method* (350) to move the common behavior.

Many writers on object orientation treat inheritance as something that should be carefully planned in advance, based on some kind of classification structure in the “real world.” Such classification structures can be a hint towards using inheritance—but just as often inheritance is something I realize during the evolution of a program, as I find common elements that I want to pull together.

An alternative to Extract Superclass is *Extract Class* (182). Here you have, essentially, a choice between using inheritance or delegation as a way to unify duplicate behavior. Often Extract Superclass is the simpler approach, so I’ll do this first knowing I can use *Replace Superclass with Delegate* (399) should I need to later.

Mechanics

- Create an empty superclass. Make the original classes its subclasses.

If needed, use *Change Function Declaration* (124) on the constructors.

- Test.
- One by one, use *Pull Up Constructor Body* (355), *Pull Up Method* (350), and *Pull Up Field* (353) to move common elements to the superclass.
- Examine remaining methods on the subclasses. See if there are common parts. If so, use *Extract Function* (106) followed by *Pull Up Method* (350).
- Check clients of the original classes. Consider adjusting them to use the superclass interface.

Example

I’m pondering these two classes, they share some common functionality—their name and the notions of annual and monthly costs:

```
class Employee {
  constructor(name, id, monthlyCost) {
    this._id = id;
    this._name = name;
    this._monthlyCost = monthlyCost;
  }
  get monthlyCost() {return this._monthlyCost;}
  get name() {return this._name;}
  get id() {return this._id;}

  get annualCost() {
    return this.monthlyCost * 12;
  }
}

class Department {
  constructor(name, staff){
    this._name = name;
    this._staff = staff;
  }
  get staff() {return this._staff.slice();}
  get name() {return this._name;}

  get totalMonthlyCost() {
    return this.staff
      .map(e => e.monthlyCost)
      .reduce((sum, cost) => sum + cost);
  }
  get headCount() {
    return this.staff.length;
  }
  get totalAnnualCost() {
    return this.totalMonthlyCost * 12;
  }
}
```

I can make the common behavior more explicit by extracting a common superclass from them.

I begin by creating an empty superclass and letting them both extend from it.

```
class Party {}

class Employee extends Party {
  constructor(name, id, monthlyCost) {
    super();
    this._id = id;
    this._name = name;
    this._monthlyCost = monthlyCost;
  }
  // rest of class...
```

```

class Department extends Party {
  constructor(name, staff){
    super();
    this._name = name;
    this._staff = staff;
  }
  // rest of class...

```

When doing Extract Superclass, I like to start with the data, which in JavaScript involves manipulating the constructor. So I start with *Pull Up Field (353)* to pull up the name.

```

class Party...
  constructor(name){
    this._name = name;
  }

class Employee...
  constructor(name, id, monthlyCost) {
    super(name);
    this._id = id;
    this._monthlyCost = monthlyCost;
  }

class Department...
  constructor(name, staff){
    super(name);
    this._staff = staff;
  }

```

As I get data up to the superclass, I can also apply *Pull Up Method (350)* on associated methods. First, the name:

```

class Party...
  get name() {return this._name;}

class Employee...
  get name() {return this._name;}

class Department...
  get name() {return this._name;}

```

I have two methods with similar bodies.

```

class Employee...
  get annualCost() {
    return this.monthlyCost * 12;
  }

```



```
class Department...
  get totalAnnualCost() {
    return this.totalMonthlyCost * 12;
  }
```

The methods they use, `monthlyCost` and `totalMonthlyCost`, have different names and different bodies—but do they represent the same intent? If so, I should use *Change Function Declaration (124)* to unify their names.

```
class Department...
  get totalAnnualCost() {
    return this.monthlyCost * 12;
  }

  get monthlyCost() { ... }
```

I then do a similar renaming to the annual costs:

```
class Department...
  get annualCost() {
    return this.monthlyCost * 12;
  }
```

I can now apply *Pull Up Method (350)* to the annual cost methods.

```
class Party...
  get annualCost() {
    return this.monthlyCost * 12;
  }
```

```
class Employee...
  get annualCost() {
    return this.monthlyCost * 12;
  }
```

```
class Department...
  get annualCost() {
    return this.monthlyCost * 12;
  }
```

Collapse Hierarchy



```
class Employee {...}  
class Salesman extends Employee {...}
```



```
class Employee {...}
```

Motivation

When I'm refactoring a class hierarchy, I'm often pulling and pushing features around. As the hierarchy evolves, I sometimes find that a class and its parent are no longer different enough to be worth keeping separate. At this point, I'll merge them together.

Mechanics

- Choose which one to remove.

I choose based on which name makes most sense in the future. If neither name is best, I'll pick one arbitrarily.

- Use *Pull Up Field (353)*, *Push Down Field (361)*, *Pull Up Method (350)*, and *Push Down Method (359)* to move all the elements into a single class.
- Adjust any references to the victim to change them to the class that will stay.
- Remove the empty class.
- Test.

Replace Subclass with Delegate



```
class Order {  
  get daysToShip() {  
    return this._warehouse.daysToShip;  
  }  
}  
  
class PriorityOrder extends Order {  
  get daysToShip() {  
    return this._priorityPlan.daysToShip;  
  }  
}
```



```
class Order {  
  get daysToShip() {  
    return (this._priorityDelegate)  
      ? this._priorityDelegate.daysToShip  
      : this._warehouse.daysToShip;  
  }  
}  
  
class PriorityOrderDelegate {  
  get daysToShip() {  
    return this._priorityPlan.daysToShip  
  }  
}
```

Motivation

If I have some objects whose behavior varies from category to category, the natural mechanism to express this is inheritance. I put all the common data and behavior in the superclass, and let each subclass add and override features as

needed. Object-oriented languages make this simple to implement and thus a familiar mechanism.

But inheritance has its downsides. Most obviously, it's a card that can only be played once. If I have more than one reason to vary something, I can only use inheritance for a single axis of variation. So, if I want to vary behavior of people by their age category and by their income level, I can either have subclasses for young and senior, or for well-off and poor—I can't have both.

A further problem is that inheritance introduces a very close relationship between classes. Any change I want to make to the parent can easily break children, so I have to be careful and understand how children derive from the superclass. This problem is made worse when the logic of the two classes resides in different modules and is looked after by different teams.

Delegation handles both of these problems. I can delegate to many different classes for different reasons. Delegation is a regular relationship between objects—so I can have a clear interface to work with, which is much less coupling than subclassing. It's therefore common to run into the problems with subclassing and apply Replace Subclass with Delegate.

There is a popular principle: "Favor object composition over class inheritance" (where composition is effectively the same as delegation). Many people take this to mean "inheritance considered harmful" and claim that we should never use inheritance. I use inheritance frequently, partly because I always know I can use Replace Subclass with Delegate should I need to change it later. Inheritance is a valuable mechanism that does the job most of the time without problems. So I reach for it first, and move onto delegation when it starts to rub badly. This usage is actually consistent with the principle—which comes from the Gang of Four book [gof] that explains how inheritance and composition work together. The principle was a reaction to the overuse of inheritance.

Those who are familiar with the Gang of Four book may find it helpful to think of this refactoring as replacing subclasses with the State or Strategy patterns. Both of these patterns are structurally the same, relying on the host delegating to a separate hierarchy. Not all cases of Replace Subclass with Delegate involve an inheritance hierarchy for the delegate (as the first example below illustrates), but setting up a hierarchy for states or strategies is often useful.

Mechanics

- If there are many callers for the constructors, apply *Replace Constructor with Factory Function* (334).
- Create an empty class for the delegate. Its constructor should take any subclass-specific data as well as, usually, a back-reference to the superclass.
- Add a field to the superclass to hold the delegate.

- Modify the creation of the subclass so that it initializes the delegate field with an instance of the delegate.

This can be done in the factory function, or in the constructor if the constructor can reliably tell whether to create the correct delegate.

- Choose a subclass method to move to the delegate class.
- Use *Move Function (198)* to move it to the delegate class. Don't remove the source's delegating code.

If the method needs elements that should move to the delegate, move them. If it needs elements that should stay in the superclass, add a field to the delegate that refers to the superclass.

- If the source method has callers outside the class, move the source's delegating code from the subclass to the superclass, guarding it with a check for the presence of the delegate. If not, apply *Remove Dead Code (237)*.

If there's more than one subclass, and you start duplicating code within them, use *Extract Superclass (375)*. In this case, any delegating methods on the source superclass no longer need a guard if the default behavior is moved to the delegate superclass.

- Test.
- Repeat until all the methods of the subclass are moved.
- Find all callers of the subclasses's constructor and change them to use the superclass constructor.
- Test.
- Use *Remove Dead Code (237)* on the subclass.

Example

I have a class that makes a booking for a show.

```
class Booking...
  constructor(show, date) {
    this._show = show;
    this._date = date;
  }
```

There is a subclass for premium booking that takes into account various extras that are available.

class PremiumBooking extends Booking...

```
constructor(show, date, extras) {
  super(show, date);
  this._extras = extras;
}
```

There are quite a few changes that the premium booking makes to what it inherits from the superclass. As is typical with this kind of programming-by-difference, in some cases the subclass overrides methods on the superclass, in others it adds new methods that are only relevant for the subclass. I won't go into all of them, but I will pick out a few interesting cases.

First, there is a simple override. Regular bookings offer a talkback after the show, but only on nonpeak days.

class Booking...

```
get hasTalkback() {
  return this._show.hasOwnProperty('talkback') && !this.isPeakDay;
}
```

Premium bookings override this to offer talkbacks on all days.

class PremiumBooking...

```
get hasTalkback() {
  return this._show.hasOwnProperty('talkback');
}
```

Determining the price is a similar override, with a twist that the premium method calls the superclass method.

class Booking...

```
get basePrice() {
  let result = this._show.price;
  if (this.isPeakDay) result += Math.round(result * 0.15);
  return result;
}
```

class PremiumBooking...

```
get basePrice() {
  return Math.round(super.basePrice + this._extras.premiumFee);
}
```

The last example is where the premium booking offers a behavior that isn't present on the superclass.

class PremiumBooking...

```
get hasDinner() {
  return this._extras.hasOwnProperty('dinner') && !this.isPeakDay;
}
```

Inheritance works well for this example. I can understand the base class without having to understand the subclass. The subclass is defined just by saying how it differs from the base case—both reducing duplication and clearly communicating what are the differences it's introducing.

Actually, it isn't quite as perfect as the previous paragraph implies. There are things in the superclass structure that only make sense due to the subclass—such as methods that have been factored in such a way as to make it easier to override just the right kinds of behavior. So although most of the time I can modify the base class without having to understand subclasses, there are occasions where such mindful ignorance of the subclasses will lead me to breaking a subclass by modifying the superclass. However, if these occasions are not too common, the inheritance pays off—provided I have good tests to detect a subclass breakage.

So why would I want to change such a happy situation by using Replace Subclass with Delegate? Inheritance is a tool that can only be used once—so if I have another reason to use inheritance, and I think it will benefit me more than the premium booking subclass, I'll need to handle premium bookings a different way. Also, I may need to change from the default booking to the premium booking dynamically—i.e., support a method like `aBooking.bePremium()`. In some cases, I can avoid this by creating a whole new object (a common example is where an HTTP request loads new data from the server). But sometimes, I need to modify a data structure and not rebuild it from scratch, and it is difficult to just replace a single booking that's referred to from many different places. In such situations, it can be useful to allow a booking to switch from default to premium and back again.

When these needs crop up, I need to apply Replace Subclass with Delegate. I have clients call the constructors of the two classes to make the bookings:

booking client

```
aBooking = new Booking(show,date);
```

premium client

```
aBooking = new PremiumBooking(show, date, extras);
```

Removing subclasses will alter all of this, so I like to encapsulate the constructor calls with *Replace Constructor with Factory Function (334)*.

top level...

```
function createBooking(show, date) {
  return new Booking(show, date);
}
function createPremiumBooking(show, date, extras) {
  return new PremiumBooking (show, date, extras);
}
```

booking client

```
aBooking = createBooking(show, date);
```

premium client

```
aBooking = createPremiumBooking(show, date, extras);
```

I now make the new delegate class. Its constructor parameters are those parameters that are only used in the subclass, together with a back-reference to the booking object. I'll need this because several subclass methods require access to data stored in the superclass. Inheritance makes this easy to do, but with a delegate I need a back-reference.

class PremiumBookingDelegate...

```
constructor(hostBooking, extras) {
  this._host = hostBooking;
  this._extras = extras;
}
```

I now connect the new delegate to the booking object. I do this by modifying the factory function for premium bookings.

top level...

```
function createPremiumBooking(show, date, extras) {
  const result = new PremiumBooking (show, date, extras);
  result._bePremium(extras);
  return result;
}
```

class Booking...

```
_bePremium(extras) {
  this._premiumDelegate = new PremiumBookingDelegate(this, extras);
}
```

I use a leading underscore on `_bePremium` to indicate that it shouldn't be part of the public interface for `Booking`. Of course, if the point of doing this refactoring is to allow a booking to mutate to premium, it can be a public method.

Alternatively, I can do all the connections in the constructor for `Booking`. In order to do that, I need some way to signal to the constructor that we have a premium booking. That could be an extra parameter, or just the use of `extras` if I can be sure that it is always present when used with a premium booking. Here, I prefer the explicitness of doing this through the factory function.

With the structures set up, it's time to start moving the behavior. The first case I'll consider is the simple override of `hasTalkback`. Here's the existing code:

class Booking...

```
get hasTalkback() {
  return this._show.hasOwnProperty('talkback') && !this.isPeakDay;
}
```



```
class PremiumBooking...
  get hasTalkback() {
    return this._show.hasOwnProperty('talkback');
  }
}
```

I use *Move Function (198)* to move the subclass method to the delegate. To make it fit its home, I route any access to superclass data with a call to `_host`.

```
class PremiumBookingDelegate...
  get hasTalkback() {
    return this._host._show.hasOwnProperty('talkback');
  }
}
```

```
class PremiumBooking...
  get hasTalkback() {
    return this._premiumDelegate.hasTalkback;
  }
}
```

I test to ensure everything is working, then delete the subclass method:

```
class PremiumBooking...
  get hasTalkback() {
      return this._premiumDelegate.hasTalkback;
  }
```

I run the tests at this point, expecting some to fail.

Now I finish the move by adding dispatch logic to the superclass method to use the delegate if it is present.

```
class Booking...
  get hasTalkback() {
    return (this._premiumDelegate
      ? this._premiumDelegate.hasTalkback
      : this._show.hasOwnProperty('talkback') && !this.isPeakDay;
    )
  }
}
```

The next case I'll look at is the base price.

```
class Booking...
  get basePrice() {
    let result = this._show.price;
    if (this.isPeakDay) result += Math.round(result * 0.15);
    return result;
  }
}
```

```
class PremiumBooking...
  get basePrice() {
    return Math.round(super.basePrice + this._extras.premiumFee);
  }
}
```

This is almost the same, but there is a wrinkle in the form of the pesky call on `super` (which is pretty common in these kinds of subclass extension cases). When I move the subclass code to the delegate, I'll need to call the parent case—but I can't just call `this._host._basePrice` without getting into an endless recursion.

I have a couple of options here. One is to apply *Extract Function* (106) on the base calculation to allow me to separate the dispatch logic from price calculation. (The rest of the move is as before.)

class Booking...

```
get basePrice() {
  return (this._premiumDelegate)
    ? this._premiumDelegate.basePrice
    : this._privateBasePrice;
}

get _privateBasePrice() {
  let result = this._show.price;
  if (this.isPeakDay) result += Math.round(result * 0.15);
  return result;
}
```

class PremiumBookingDelegate...

```
get basePrice() {
  return Math.round(this._host._privateBasePrice + this._extras.premiumFee);
}
```

Alternatively, I can recast the delegate's method as an extension of the base method.

class Booking...

```
get basePrice() {
  let result = this._show.price;
  if (this.isPeakDay) result += Math.round(result * 0.15);
  return (this._premiumDelegate)
    ? this._premiumDelegate.extendBasePrice(result)
    : result;
}
```

class PremiumBookingDelegate...

```
extendBasePrice(base) {
  return Math.round(base + this._extras.premiumFee);
}
```

Both work reasonably here; I have a slight preference for the latter as it's a bit smaller.

The last case is a method that only exists on the subclass.

```
class PremiumBooking...
```

```
  get hasDinner() {
    return this._extras.hasOwnProperty('dinner') && !this.isPeakDay;
  }
```

I move it from the subclass to the delegate:

```
class PremiumBookingDelegate...
```

```
  get hasDinner() {
    return this._extras.hasOwnProperty('dinner') && !this._host.isPeakDay;
  }
```

I then add dispatch logic to Booking:

```
class Booking...
```

```
  get hasDinner() {
    return (this._premiumDelegate)
      ? this._premiumDelegate.hasDinner
      : undefined;
  }
```

In JavaScript, accessing a property on an object where it isn't defined returns `undefined`, so I do that here. (Although my every instinct is to have it raise an error, which would be the case in other object-oriented dynamic languages I'm used to.)

Once I've moved all the behavior out of the subclass, I can change the factory method to return the superclass—and, once I've run tests to ensure all is well, delete the subclass.

top level...

```
function createPremiumBooking(show, date, extras) {
  const result = new PremiumBooking (show, date, extras);
  result._bePremium(extras);
  return result;
}
```

```
class PremiumBooking extends Booking...
```

This is one of those refactorings where I don't feel that refactoring alone improves the code. Inheritance handles this situation very well, whereas using delegation involves adding dispatch logic, two-way references, and thus extra complexity. The refactoring may still be worthwhile, since the advantage of a mutable premium status, or a need to use inheritance for other purposes, may outweigh the disadvantage of losing inheritance.

Example: Replacing a Hierarchy

The previous example showed using Replace Subclass with Delegate on a single subclass, but I can do the same thing with an entire hierarchy.

```
function createBird(data) {
  switch (data.type) {
    case 'EuropeanSwallow':
      return new EuropeanSwallow(data);
    case 'AfricanSwallow':
      return new AfricanSwallow(data);
    case 'NorwegianBlueParrot':
      return new NorwegianBlueParrot(data);
    default:
      return new Bird(data);
  }
}

class Bird {
  constructor(data) {
    this._name = data.name;
    this._plumage = data.plumage;
  }
  get name() {return this._name;}

  get plumage() {
    return this._plumage || "average";
  }
  get airSpeedVelocity() {return null;}
}

class EuropeanSwallow extends Bird {
  get airSpeedVelocity() {return 35;}
}

class AfricanSwallow extends Bird {
  constructor(data) {
    super (data);
    this._numberOfCoconuts = data.numberOfCoconuts;
  }
  get airSpeedVelocity() {
    return 40 - 2 * this._numberOfCoconuts;
  }
}

class NorwegianBlueParrot extends Bird {
  constructor(data) {
    super (data);
    this._voltage = data.voltage;
    this._isNailed = data.isNailed;
  }

  get plumage() {
    if (this._voltage > 100) return "scorched";
    else return this._plumage || "beautiful";
  }
}
```

```

    get airSpeedVelocity() {
        return (this._isNailed) ? 0 : 10 + this._voltage / 10;
    }
}

```

The system will shortly be making a big difference between birds tagged in the wild and those tagged in captivity. That difference could be modeled as two subclasses for Bird: WildBird and CaptiveBird. However, I can only use inheritance once, so if I want to use subclasses for wild versus captive, I'll have to remove them for the species.

When several subclasses are involved, I'll tackle them one at a time, starting with a simple one—in this case, EuropeanSwallow. I create an empty delegate class for the delegate.

```

class EuropeanSwallowDelegate {
}

```

I don't put in any data or back-reference parameters yet. For this example, I'll introduce them as I need them.

I need to decide where to handle the initialization of the delegate field. Here, since I have all the information in the single data argument to the constructor, I decide to do it in the constructor. Since there are several delegates I could add, I make a function to select the correct one based on the type code in the document.

```

class Bird...
    constructor(data) {
        this._name = data.name;
        this._plumage = data.plumage;
        this._speciesDelegate = this.selectSpeciesDelegate(data);
    }

    selectSpeciesDelegate(data) {
        switch(data.type) {
            case 'EuropeanSwallow':
                return new EuropeanSwallowDelegate();
            default: return null;
        }
    }
}

```

Now I have the structure set up, I can apply *Move Function (198)* to the European swallow's air speed velocity.

```

class EuropeanSwallowDelegate...
    get airSpeedVelocity() {return 35;}

class EuropeanSwallow...
    get airSpeedVelocity() {return this._speciesDelegate.airSpeedVelocity;}

```

I change `airSpeedVelocity` on the superclass to call a delegate, if present.

class Bird...

```
get airSpeedVelocity() {
  return this._speciesDelegate ? this._speciesDelegate.airSpeedVelocity : null;
}
```

I remove the subclass.

```
class EuropeanSwallow extends Bird {
  get airSpeedVelocity() {return this._speciesDelegate.airSpeedVelocity;}
}
```

top level...

```
function createBird(data) {
  switch (data.type) {
    case 'EuropeanSwallow':
    return new EuropeanSwallow(data);
    case 'AfricanSwallow':
      return new AfricanSwallow(data);
    case 'NorwegianBlueParrot':
      return new NorwegianBlueParrot(data);
    default:
      return new Bird(data);
  }
}
```

Next I'll tackle the African swallow. I create a class; this time, the constructor needs the data document.

class AfricanSwallowDelegate...

```
constructor(data) {
  this._numberOfCoconuts = data.numberOfCoconuts;
}
```

class Bird...

```
selectSpeciesDelegate(data) {
  switch(data.type) {
    case 'EuropeanSwallow':
      return new EuropeanSwallowDelegate();
    case 'AfricanSwallow':
    return new AfricanSwallowDelegate(data);
    default: return null;
  }
}
```

I use *Move Function (198)* on `airSpeedVelocity`.

```

class AfricanSwallowDelegate...
    get airSpeedVelocity() {
        return 40 - 2 * this._numberOfCoconuts;
    }

class AfricanSwallow...
    get airSpeedVelocity() {
        return this._speciesDelegate.airSpeedVelocity;
    }

```

I can now remove the African swallow subclass.

```

class AfricanSwallow extends Bird {
    // all of the body ...
}

function createBird(data) {
    switch (data.type) {
        case 'AfricanSwallow':
            return new AfricanSwallow(data);
        case 'NorwegianBlueParrot':
            return new NorwegianBlueParrot(data);
        default:
            return new Bird(data);
    }
}

```

Now for the Norwegian blue. Creating the class and moving the air speed velocity uses the same steps as before, so I'll just show the result.

```

class Bird...
    selectSpeciesDelegate(data) {
        switch(data.type) {
            case 'EuropeanSwallow':
                return new EuropeanSwallowDelegate();
            case 'AfricanSwallow':
                return new AfricanSwallowDelegate(data);
            case 'NorwegianBlueParrot':
                return new NorwegianBlueParrotDelegate(data);
            default: return null;
        }
    }
}

class NorwegianBlueParrotDelegate...
    constructor(data) {
        this._voltage = data.voltage;
        this._isNailed = data.isNailed;
    }
    get airSpeedVelocity() {
        return (this._isNailed) ? 0 : 10 + this._voltage / 10;
    }
}

```

All well and good, but the Norwegian blue overrides the `plumage` property, which I didn't have to deal with for the other cases. The initial *Move Function (198)* is simple enough, albeit with the need to modify the constructor to put in a back-reference to the bird.

```
class NorwegianBlueParrot...
    get plumage() {
        return this._speciesDelegate.plumage;
    }

class NorwegianBlueParrotDelegate...
    get plumage() {
        if (this._voltage > 100) return "scorched";
        else return this._bird._plumage || "beautiful";
    }

    constructor(data, bird) {
        this._bird = bird;
        this._voltage = data.voltage;
        this._isNailed = data.isNailed;
    }

class Bird...
    selectSpeciesDelegate(data) {
        switch(data.type) {
            case 'EuropeanSwallow':
                return new EuropeanSwallowDelegate();
            case 'AfricanSwallow':
                return new AfricanSwallowDelegate(data);
            case 'NorwegianBlueParrot':
                return new NorwegianBlueParrotDelegate(data, this);
            default: return null;
        }
    }
}
```

The tricky step is how to remove the subclass method for `plumage`. If I do

```
class Bird...
    get plumage() {
        if (this._speciesDelegate)
            return this._speciesDelegate.plumage;
        else
            return this._plumage || "average";
    }
}
```

then I'll get a bunch of errors because there is no `plumage` property on the other species' delegate classes.

I could use a more precise conditional:

```
class Bird...
  get plumage() {
    if (this._speciesDelegate instanceof NorwegianBlueParrotDelegate)
      return this._speciesDelegate.plumage;
    else
      return this._plumage || "average";
  }
```

But I hope that smells as much of decomposing parrot to you as it does to me. It's almost never a good idea to use an explicit class check like this.

Another option is to implement the default case on the other delegates.

```
class Bird...
  get plumage() {
    if (this._speciesDelegate)
      return this._speciesDelegate.plumage;
    else
      return this._plumage || "average";
  }
```

```
class EuropeanSwallowDelegate...
  get plumage() {
    return this._bird._plumage || "average";
  }
```

```
class AfricanSwallowDelegate...
  get plumage() {
    return this._bird._plumage || "average";
  }
```

But this duplicates the default method for plumage. And if that's not bad enough, I also get some bonus duplication in the constructors to assign the back-reference.

The solution to the duplication is, naturally, inheritance—I apply *Extract Superclass* (375) to the species delegates:

```
class SpeciesDelegate {
  constructor(data, bird) {
    this._bird = bird;
  }
  get plumage() {
    return this._bird._plumage || "average";
  }
}

class EuropeanSwallowDelegate extends SpeciesDelegate {
```

```

class AfricanSwallowDelegate extends SpeciesDelegate {
  constructor(data, bird) {
    super(data, bird);
    this._numberOfCoconuts = data.numberOfCoconuts;
  }

class NorwegianBlueParrotDelegate extends SpeciesDelegate {
  constructor(data, bird) {
    super(data, bird);
    this._voltage = data.voltage;
    this._isNailed = data.isNailed;
  }

```

Indeed, now I have a superclass, I can move any default behavior from Bird to SpeciesDelegate by ensuring there's always something in the speciesDelegate field.

```

class Bird...
  selectSpeciesDelegate(data) {
    switch(data.type) {
      case 'EuropeanSwallow':
        return new EuropeanSwallowDelegate(data, this);
      case 'AfricanSwallow':
        return new AfricanSwallowDelegate(data, this);
      case 'NorwegianBlueParrot':
        return new NorwegianBlueParrotDelegate(data, this);
      default: return new SpeciesDelegate(data, this);
    }
  }
  // rest of bird's code...

  get plumage() {return this._speciesDelegate.plumage;}

  get airSpeedVelocity() {return this._speciesDelegate.airSpeedVelocity;}

class SpeciesDelegate...
  get airSpeedVelocity() {return null;}

```

I like this, as it simplifies the delegating methods on Bird. I can easily see which behavior is delegated to the species delegate and which stays behind.

Here's the final state of these classes:

```

function createBird(data) {
  return new Bird(data);
}

```

```

class Bird {
  constructor(data) {
    this._name = data.name;
    this._plumage = data.plumage;
    this._speciesDelegate = this.selectSpeciesDelegate(data);
  }
  get name() {return this._name;}
  get plumage() {return this._speciesDelegate.plumage;}
  get airSpeedVelocity() {return this._speciesDelegate.airSpeedVelocity;}

  selectSpeciesDelegate(data) {
    switch(data.type) {
      case 'EuropeanSwallow':
        return new EuropeanSwallowDelegate(data, this);
      case 'AfricanSwallow':
        return new AfricanSwallowDelegate(data, this);
      case 'NorwegianBlueParrot':
        return new NorwegianBlueParrotDelegate(data, this);
      default: return new SpeciesDelegate(data, this);
    }
  }
  // rest of bird's code...
}

class SpeciesDelegate {
  constructor(data, bird) {
    this._bird = bird;
  }
  get plumage() {
    return this._bird._plumage || "average";
  }
  get airSpeedVelocity() {return null;}
}

class EuropeanSwallowDelegate extends SpeciesDelegate {
  get airSpeedVelocity() {return 35;}
}

class AfricanSwallowDelegate extends SpeciesDelegate {
  constructor(data, bird) {
    super(data,bird);
    this._numberOfCoconuts = data.numberOfCoconuts;
  }
  get airSpeedVelocity() {
    return 40 - 2 * this._numberOfCoconuts;
  }
}

```

```
class NorwegianBlueParrotDelegate extends SpeciesDelegate {  
  constructor(data, bird) {  
    super(data, bird);  
    this._voltage = data.voltage;  
    this._isNailed = data.isNailed;  
  }  
  get airSpeedVelocity() {  
    return (this._isNailed) ? 0 : 10 + this._voltage / 10;  
  }  
  get plumage() {  
    if (this._voltage > 100) return "scorched";  
    else return this._bird._plumage || "beautiful";  
  }  
}
```

This example replaces the original subclasses with a delegate, but there is still a very similar inheritance structure in `SpeciesDelegate`. Have I gained anything from this refactoring, other than freeing up inheritance on `Bird`? The species inheritance is now more tightly scoped, covering just the data and functions that vary due to the species. Any code that's the same for all species remains on `Bird` and its future subclasses.

I could apply the same idea of creating a superclass delegate to the booking example earlier. This would allow me to replace those methods on `Booking` that have dispatch logic with simple calls to the delegate and letting its inheritance sort out the dispatch. However, it's nearly dinner time, so I'll leave that as an exercise for the reader.

These examples illustrate that the phrase "Favor object composition over class inheritance" might better be said as "Favor a judicious mixture of composition and inheritance over either alone"—but I fear that is not as catchy.

Replace Superclass with Delegate

formerly: *Replace Inheritance with Delegation*



```
class List {...}
class Stack extends List {...}
```



```
class Stack {
  constructor() {
    this._storage = new List();
  }
}
class List {...}
```

Motivation

In object-oriented programs, inheritance is a powerful and easily available way to reuse existing functionality. I inherit from some existing class, then override and add additional features. But subclassing can be done in a way that leads to confusion and complication.

One of the classic examples of mis-inheritance from the early days of objects was making a stack be a subclass of list. The idea that led to this was reusing of list's data storage and operations to manipulate it. While it's good to reuse, this inheritance had a problem: All the operations of the list were present on the interface of the stack, although most of them were not applicable to a stack. A better approach is to make the list into a field of the stack and delegate the necessary operations to it.

This is an example of one reason to use Replace Superclass with Delegate—if functions of the superclass don't make sense on the subclass, that's a sign that I shouldn't be using inheritance to use the superclass's functionality.

As well as using all the functions of the superclass, it should also be true that every instance of the subclass is an instance of the superclass and a valid object in all cases where we're using the superclass. If I have a car model class, with things like name and engine size, I might think I could reuse these features to represent a physical car, adding functions for VIN number and manufacturing date. This is a common, and often subtle, modeling mistake which I've called the type-instance homonym [mf-tih].

These are both examples of problems leading to confusion and errors—which can be easily avoided by replacing inheritance with delegation to a separate object. Using delegation makes it clear that it is a separate thing—one where only some of the functions carry over.

Even in cases where the subclass is reasonable modeling, I use Replace Superclass with Delegate because the relationship between a sub- and superclass is highly coupled, with the subclass easily broken by changes in the superclass. The downside is that I need to write a forwarding function for any function that is the same in the host and in the delegate—but, fortunately, even though such forwarding functions are boring to write, they are too simple to get wrong.

As a consequence of all this, some people advise avoiding inheritance entirely—but I don't agree with that. Provided the appropriate semantic conditions apply (every method on the supertype applies to the subtype, every instance of the subtype is an instance of the supertype), inheritance is a simple and effective mechanism. I can easily apply Replace Superclass with Delegate should the situation change and inheritance is no longer the best option. So my advice is to (mostly) use inheritance first, and apply Replace Superclass with Delegate when (and if) it becomes a problem.

Mechanics

- Create a field in the subclass that refers to the superclass object. Initialize this delegate reference to a new instance.
- For each element of the superclass, create a forwarding function in the subclass that forwards to the delegate reference. Test after forwarding each consistent group.

Most of the time you can test after each function that's forwarded, but, for example, get/set pairs can only be tested once both have been moved.

- When all superclass elements have been overridden with forwarders, remove the inheritance link.

Example

I recently was consulting for an old town's library of ancient scrolls. They keep details of their scrolls in a catalog. Each scroll has an ID number and records its title and list of tags.

class CatalogItem...

```
constructor(id, title, tags) {
  this._id = id;
  this._title = title;
  this._tags = tags;
}

get id() {return this._id;}
get title() {return this._title;}
hasTag(arg) {return this._tags.includes(arg);}
```

One of the things that scrolls need is regular cleaning. The code for that uses the catalog item and extends it with the data it needs for cleaning.

class Scroll extends CatalogItem...

```
constructor(id, title, tags, dateLastCleaned) {
  super(id, title, tags);
  this._lastCleaned = dateLastCleaned;
}

needsCleaning(targetDate) {
  const threshold = this.hasTag("revered") ? 700 : 1500;
  return this.daysSinceLastCleaning(targetDate) > threshold ;
}

daysSinceLastCleaning(targetDate) {
  return this._lastCleaned.until(targetDate, ChronoUnit.DAYS);
}
```

This is an example of a common modeling error. There is a difference between the physical scroll and the catalog item. The scroll describing the treatment for the greyscale disease may have several copies, but be just one item in the catalog.

It many situations, I can get away with an error like this. I can think of the title and tags as copies of data in the catalog. Should this data never change, I can get away with this representation. But if I need to update either, I must be careful to ensure that all copies of the same catalog item are updated correctly.

Even without this issue, I'd still want to change the relationship. Using catalog item as a superclass to scroll is likely to confuse programmers in the future, and is thus a poor model to work with.

I begin by creating a property in `Scroll` that refers to the catalog item, initializing it with a new instance.

class Scroll extends CatalogItem...

```
constructor(id, title, tags, dateLastCleaned) {
  super(id, title, tags);
  this._catalogItem = new CatalogItem(id, title, tags);
  this._lastCleaned = dateLastCleaned;
}
```

I create forwarding methods for each element of the superclass that I use on the subclass.

class Scroll...

```
get id() {return this._catalogItem.id;}
get title() {return this._catalogItem.title;}
hasTag(aString) {return this._catalogItem.hasTag(aString);}
```

I remove the inheritance link to the catalog item.

```
class Scroll extends CatalogItem{
  constructor(id, title, tags, dateLastCleaned) {
    super(id, title, tags);
    this._catalogItem = new CatalogItem(id, title, tags);
    this._lastCleaned = dateLastCleaned;
  }
}
```

Breaking the inheritance link finishes the basic Replace Superclass with Delegate refactoring, but there is something more I need to do in this case.

The refactoring shifts the role of the catalog item to that of a component of scroll; each scroll contains a unique instance of a catalog item. In many cases where I do this refactoring, this is enough. However, in this situation a better model is to link the greyscale catalog item to the six scrolls in the library that are copies of that writing. Doing this is, essentially, *Change Value to Reference* (256).

There's a problem that I have to fix, however, before I use *Change Value to Reference* (256). In the original inheritance structure, the scroll used the catalog item's ID field to store its ID. But if I treat the catalog item as a reference, it needs to use that ID for the catalog item ID rather than the scroll ID. This means I need to create an ID field on scroll and use that instead of one in catalog item. It's a sort-of move, sort-of split.

class Scroll...

```
constructor(id, title, tags, dateLastCleaned) {
  this._id = id;
  this._catalogItem = new CatalogItem(null, title, tags);
  this._lastCleaned = dateLastCleaned;
}

get id() {return this._id;}
```


Creating a catalog item with a null ID would usually raise red flags and cause alarms to sound. But that's just temporary while I get things into shape. Once I've done that, the scrolls will refer to a shared catalog item with its proper ID.

Currently the scrolls are loaded as part of a load routine.

load routine...

```
const scrolls = aDocument
  .map(record => new Scroll(record.id,
                           record.catalogData.title,
                           record.catalogData.tags,
                           LocalDate.parse(record.lastCleaned)));
```

The first step in *Change Value to Reference (256)* is finding or creating a repository. I find there is a repository that I can easily import into the load routine. The repository supplies catalog items indexed by an ID. My next task is to see how to get that ID into the constructor of the scroll. Fortunately, it's present in the input data and was being ignored as it wasn't useful when using inheritance. With that sorted out, I can now use *Change Function Declaration (124)* to add both the catalog and the catalog item's ID to the constructor parameters.

load routine...

```
const scrolls = aDocument
  .map(record => new Scroll(record.id,
                           record.catalogData.title,
                           record.catalogData.tags,
                           LocalDate.parse(record.lastCleaned),
                           record.catalogData.id,
                           catalog));
```

class Scroll...

```
constructor(id, title, tags, dateLastCleaned, catalogID, catalog) {
  this._id = id;
  this._catalogItem = new CatalogItem(null, title, tags);
  this._lastCleaned = dateLastCleaned;
}
```

I now modify the constructor to use the catalog ID to look up the catalog item and use it instead of creating a new one.

class Scroll...

```
constructor(id, title, tags, dateLastCleaned, catalogID, catalog) {
  this._id = id;
  this._catalogItem = catalog.get(catalogID);
  this._lastCleaned = dateLastCleaned;
}
```

I no longer need the title and tags passed into the constructor, so I use *Change Function Declaration (124)* to remove them.

load routine...

```
const scrolls = aDocument
  .map(record => new Scroll(record.id,
    record.catalogData.title,
    record.catalogData.tags,
    LocalDate.parse(record.lastCleaned),
    record.catalogData.id,
    catalog));
```

class Scroll...

```
constructor(id, title, tags, dateLastCleaned, catalogID, catalog) {
  this._id = id;
  this._catalogItem = catalog.get(catalogID);
  this._lastCleaned = dateLastCleaned;
}
```

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Smells

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Comments (84)	Extract Function (106), Change Function Declaration (124), Introduce Assertion (302)
Data Class (83)	Encapsulate Record (162), Remove Setting Method (331), Move Function (198), Extract Function (106), Split Phase (154)
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