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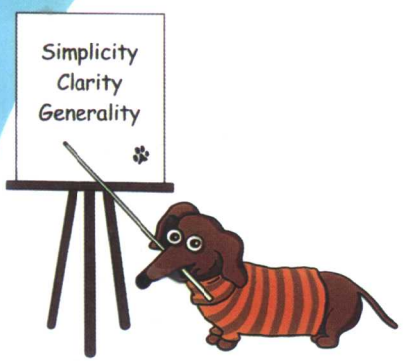
程序设计实践

（英文版）

The Practice of Programming

Brian W. Kernighan
Rob Pike



ADDISON-WESLEY PROFESSIONAL COMPUTING SERIES

（美）Brian W. Kernighan
Rob Pike 著

机械工业出版社
China Machine Press

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出版者的话

文艺复兴以降，源远流长的科学精神和逐步形成的学术规范，使西方国家在自然科学的各个领域取得了垄断性的优势；也正是这样的传统，使美国在信息技术发展的六十多年间名家辈出、独领风骚。在商业化的进程中，美国的产业界与教育界越来越紧密地结合，计算机学科中的许多泰山北斗同时身处科研和教学的最前线，由此而产生的经典科学著作，不仅擘划了研究的范畴，还揭橥了学术的源变，既遵循学术规范，又自有学者个性，其价值并不会因年月的流逝而减退。

近年，在全球信息化大潮的推动下，我国的计算机产业发展迅猛，对专业人才的需求日益迫切。这对计算机教育界和出版界都既是机遇，也是挑战；而专业教材的建设在教育战略上显得举足轻重。在我国信息技术发展时间较短、从业人员较少的现状下，美国等发达国家在其计算机科学发展的几十年间积淀的经典教材仍有许多值得借鉴之处。因此，引进一批国外优秀计算机教材将对我国计算机教育事业的发展起积极的推动作用，也是与世界接轨、建设真正的世界一流大学的必由之路。

机械工业出版社华章图文信息有限公司较早意识到“出版要为教育服务”。自1998年始，华章公司就将工作重点放在了遴选、移译国外优秀教材上。经过几年的不懈努力，我们与Prentice Hall，Addison-Wesley，McGraw-Hill，Morgan Kaufmann等世界著名出版公司建立了良好的合作关系，从它们现有的数百种教材中甄选出Tanenbaum，Stroustrup，Kernighan，Jim Gray等大师名家的一批经典作品，以“计算机科学丛书”为总称出版，供读者学习、研究及庋藏。大理石纹理的封面，也正体现了这套丛书的品位和格调。

“计算机科学丛书”的出版工作得到了国内外学者的鼎力襄助，国内的专家不仅提供了中肯的选题指导，还不辞劳苦地担任了翻译和审校的工作；而原书的作者也相当关注其作品在中国的传播，有的还专诚为其书的中译本作序。迄今，“计算机科学丛书”已经出版了近百个品种，这些书籍在读者中树立了良好的口碑，并被许多高校采用为正式教材和参考书籍，为进一步推广与发展打下了坚实的基础。

NS 2/06

随着学科建设的初步完善和教材改革的逐渐深化，教育界对国外计算机教材的需求和应用都步入一个新的阶段。为此，华章公司将加大引进教材的力度，在“华章教育”的总规划之下出版三个系列的计算机教材：针对本科生的核心课程，剔抉外版菁华而成“国外经典教材”系列；对影印版的教材，则单独开辟出“经典原版书库”；定位在高级教程和专业参考的“计算机科学丛书”还将保持原来的风格，继续出版新的品种。为了保证这三套丛书的权威性，同时也为了更好地为学校和老师们服务，华章公司聘请了中国科学院、北京大学、清华大学、国防科技大学、复旦大学、上海交通大学、南京大学、浙江大学、中国科技大学、哈尔滨工业大学、西安交通大学、中国人民大学、北京航空航天大学、北京邮电大学、中山大学、解放军理工大学、郑州大学、湖北工学院、中国国家信息安全测评认证中心等国内重点大学和科研机构在计算机的各个领域的著名学者组成“专家指导委员会”，为我们提供选题意见和出版监督。

“经典原版书库”是响应教育部提出的使用原版国外教材的号召，为国内高校的计算机教学度身订造的。在广泛地征求并听取丛书的“专家指导委员会”的意见后，我们最终选定了这30多种篇幅内容适度、讲解鞭辟入里的教材，其中的大部分已经被M.I.T.、Stanford、U.C. Berkley、C.M.U.等世界名牌大学采用。丛书不仅涵盖了程序设计、数据结构、操作系统、计算机体系结构、数据库、编译原理、软件工程、图形学、通信与网络、离散数学等国内大学计算机专业普遍开设的核心课程，而且各具特色——有的出自语言设计者之手、有的历三十年而不衰、有的已被全世界的几百所高校采用。在这些圆熟通博的名师大作的指引之下，读者必将在计算机科学的宫殿中由登堂而入室。

权威的作者、经典的教材、一流的译者、严格的审校、精细的编辑，这些因素使我们的图书有了质量的保证，但我们的目标是尽善尽美，而反馈的意见正是我们达到这一终极目标的重要帮助。教材的出版只是我们的后续服务的起点。华章公司欢迎老师和读者对我们的工作提出建议或给予指正，我们的联系方法如下：

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Preface

Have you ever...

wasted a lot of time coding the wrong algorithm?
used a data structure that was much too complicated?
tested a program but missed an obvious problem?
spent a day looking for a bug you should have found in five minutes?
needed to make a program run three times faster and use less memory?
struggled to move a program from a workstation to a PC or vice versa?
tried to make a modest change in someone else's program?
rewritten a program because you couldn't understand it?

Was it fun?

These things happen to programmers all the time. But dealing with such problems is often harder than it should be because topics like testing, debugging, portability, performance, design alternatives, and style—the *practice* of programming—are not usually the focus of computer science or programming courses. Most programmers learn them haphazardly as their experience grows, and a few never learn them at all.

In a world of enormous and intricate interfaces, constantly changing tools and languages and systems, and relentless pressure for more of everything, one can lose sight of the basic principles—simplicity, clarity, generality—that form the bedrock of good software. One can also overlook the value of tools and notations that mechanize some of software creation and thus enlist the computer in its own programming.

Our approach in this book is based on these underlying, interrelated principles, which apply at all levels of computing. These include *simplicity*, which keeps programs short and manageable; *clarity*, which makes sure they are easy to understand, for people as well as machines; *generality*, which means they work well in a broad range of situations and adapt well as new situations arise; and *automation*, which lets the machine do the work for us, freeing us from mundane tasks. By looking at computer programming in a variety of languages, from algorithms and data structures through design, debugging, testing, and performance improvement, we can illustrate

universal engineering concepts that are independent of language, operating system, or programming paradigm.

This book comes from many years of experience writing and maintaining a lot of software, teaching programming courses, and working with a wide variety of programmers. We want to share lessons about practical issues, to pass on insights from our experience, and to suggest ways for programmers of all levels to be more proficient and productive.

We are writing for several kinds of readers. If you are a student who has taken a programming course or two and would like to be a better programmer, this book will expand on some of the topics for which there wasn't enough time in school. If you write programs as part of your work, but in support of other activities rather than as the goal in itself, the information will help you to program more effectively. If you are a professional programmer who didn't get enough exposure to such topics in school or who would like a refresher, or if you are a software manager who wants to guide your staff in the right direction, the material here should be of value.

We hope that the advice will help you to write better programs. The only prerequisite is that you have done some programming, preferably in C, C++ or Java. Of course the more experience you have, the easier it will be; nothing can take you from neophyte to expert in 21 days. Unix and Linux programmers will find some of the examples more familiar than will those who have used only Windows and Macintosh systems, but programmers from any environment should discover things to make their lives easier.

The presentation is organized into nine chapters, each focusing on one major aspect of programming practice.

Chapter 1 discusses programming style. Good style is so important to good programming that we have chosen to cover it first. Well-written programs are better than badly-written ones—they have fewer errors and are easier to debug and to modify—so it is important to think about style from the beginning. This chapter also introduces an important theme in good programming, the use of idioms appropriate to the language being used.

Algorithms and data structures, the topics of Chapter 2, are the core of the computer science curriculum and a major part of programming courses. Since most readers will already be familiar with this material, our treatment is intended as a brief review of the handful of algorithms and data structures that show up in almost every program. More complex algorithms and data structures usually evolve from these building blocks, so one should master the basics.

Chapter 3 describes the design and implementation of a small program that illustrates algorithm and data structure issues in a realistic setting. The program is implemented in five languages; comparing the versions shows how the same data structures are handled in each, and how expressiveness and performance vary across a spectrum of languages.

Interfaces between users, programs, and parts of programs are fundamental in programming and much of the success of software is determined by how well interfaces are designed and implemented. Chapter 4 shows the evolution of a small library for parsing a widely used data format. Even though the example is small, it illustrates many of the concerns of interface design: abstraction, information hiding, resource management, and error handling.

Much as we try to write programs correctly the first time, bugs, and therefore debugging, are inevitable. Chapter 5 gives strategies and tactics for systematic and effective debugging. Among the topics are the signatures of common bugs and the importance of "numerology," where patterns in debugging output often indicate where a problem lies.

Testing is an attempt to develop a reasonable assurance that a program is working correctly and that it stays correct as it evolves. The emphasis in Chapter 6 is on systematic testing by hand and machine. Boundary condition tests probe at potential weak spots. Mechanization and test scaffolds make it easy to do extensive testing with modest effort. Stress tests provide a different kind of testing than typical users do and ferret out a different class of bugs.

Computers are so fast and compilers are so good that many programs are fast enough the day they are written. But others are too slow, or they use too much memory, or both. Chapter 7 presents an orderly way to approach the task of making a program use resources efficiently, so that the program remains correct and sound as it is made more efficient.

Chapter 8 covers portability. Successful programs live long enough that their environment changes, or they must be moved to new systems or new hardware or new countries. The goal of portability is to reduce the maintenance of a program by minimizing the amount of change necessary to adapt it to a new environment.

Computing is rich in languages, not just the general-purpose ones that we use for the bulk of programming, but also many specialized languages that focus on narrow domains. Chapter 9 presents several examples of the importance of notation in computing, and shows how we can use it to simplify programs, to guide implementations, and even to help us write programs that write programs.

To talk about programming, we have to show a lot of code. Most of the examples were written expressly for the book, although some small ones were adapted from other sources. We've tried hard to write our own code well, and have tested it on half a dozen systems directly from the machine-readable text. More information is available at the web site for *The Practice of Programming*:

```
http://tpop.awl.com
```

The majority of the programs are in C, with a number of examples in C++ and Java and some brief excursions into scripting languages. At the lowest level, C and C++ are almost identical and our C programs are valid C++ programs as well. C++ and Java are lineal descendants of C, sharing more than a little of its syntax and much of its efficiency and expressiveness, while adding richer type systems and libraries.

In our own work, we routinely use all three of these languages, and many others. The choice of language depends on the problem: operating systems are best written in an efficient and unrestrictive language like C or C++; quick prototypes are often easiest in a command interpreter or a scripting language like Awk or Perl; for user interfaces, Visual Basic and Tcl/Tk are strong contenders, along with Java.

There is an important pedagogical issue in choosing a language for our examples. Just as no language solves all problems equally well, no single language is best for presenting all topics. Higher-level languages preempt some design decisions. If we use a lower-level language, we get to consider alternative answers to the questions; by exposing more of the details, we can talk about them better. Experience shows that even when we use the facilities of high-level languages, it's invaluable to know how they relate to lower-level issues; without that insight, it's easy to run into performance problems and mysterious behavior. So we will often use C for our examples, even though in practice we might choose something else.

For the most part, however, the lessons are independent of any particular programming language. The choice of data structure is affected by the language at hand; there may be few options in some languages while others might support a variety of alternatives. But the way to approach making the choice will be the same. The details of how to test and debug are different in different languages, but strategies and tactics are similar in all. Most of the techniques for making a program efficient can be applied in any language.

Whatever language you write in, your task as a programmer is to do the best you can with the tools at hand. A good programmer can overcome a poor language or a clumsy operating system, but even a great programming environment will not rescue a bad programmer. We hope that, no matter what your current experience and skill, this book will help you to program better and enjoy it more.

We are deeply grateful to friends and colleagues who read drafts of the manuscript and gave us many helpful comments. Jon Bentley, Russ Cox, John Lakos, John Linderman, Peter Memishian, Ian Lance Taylor, Howard Trickey, and Chris Van Wyk read the manuscript, some more than once, with exceptional care and thoroughness. We are indebted to Tom Cargill, Chris Cleeland, Steve Dewhurst, Eric Grosse, Andrew Herron, Gerard Holzmann, Doug McIlroy, Paul McNamee, Peter Nelson, Dennis Ritchie, Rich Stevens, Tom Szymanski, Kentaro Toyama, John Wait, Daniel C. Wang, Peter Weinberger, Margaret Wright, and Cliff Young for invaluable comments on drafts at various stages. We also appreciate good advice and thoughtful suggestions from Al Aho, Ken Arnold, Chuck Bigelow, Joshua Bloch, Bill Coughran, Bob Flandrena, Renée French, Mark Kernighan, Andy Koenig, Sape Mullender, Evi Nemeth, Marty Rabinowitz, Mark V. Shaney, Bjarne Stroustrup, Ken Thompson, and Phil Wadler. Thank you all.

Brian W. Kernighan

Rob Pike

Contents

1

Style

It is an old observation that the best writers sometimes disregard the rules of rhetoric. When they do so, however, the reader will usually find in the sentence some compensating merit, attained at the cost of the violation. Unless he is certain of doing as well, he will probably do best to follow the rules.

William Strunk and E. B. White, *The Elements of Style*

This fragment of code comes from a large program written many years ago:

```
if ( (country == SING) || (country == BRNI) ||
     (country == POL) || (country == ITALY) )
{
        /*
         * If the country is Singapore, Brunei or Poland
         * then the current time is the answer time
         * rather than the off hook time.
         * Reset answer time and set day of week.
         */
        ...
```

It's carefully written, formatted, and commented, and the program it comes from works extremely well; the programmers who created this system are rightly proud of what they built. But this excerpt is puzzling to the casual reader. What relationship links Singapore, Brunei, Poland and Italy? Why isn't Italy mentioned in the comment? Since the comment and the code differ, one of them must be wrong. Maybe both are. The code is what gets executed and tested, so it's more likely to be right; probably the comment didn't get updated when the code did. The comment doesn't say enough about the relationship among the three countries it does mention; if you had to maintain this code, you would need to know more.

The few lines above are typical of much real code: mostly well done, but with some things that could be improved.

This book is about the practice of programming—how to write programs for real. Our purpose is to help you to write software that works at least as well as the program this example was taken from, while avoiding trouble spots and weaknesses. We will talk about writing better code from the beginning and improving it as it evolves.

We are going to start in an unusual place, however, by discussing programming style. The purpose of style is to make the code easy to read for yourself and others, and good style is crucial to good programming. We want to talk about it first so you will be sensitive to it as you read the code in the rest of the book.

There is more to writing a program than getting the syntax right, fixing the bugs, and making it run fast enough. Programs are read not only by computers but also by programmers. A well-written program is easier to understand and to modify than a poorly-written one. The discipline of writing well leads to code that is more likely to be correct. Fortunately, this discipline is not hard.

The principles of programming style are based on common sense guided by experience, not on arbitrary rules and prescriptions. Code should be clear and simple—straightforward logic, natural expression, conventional language use, meaningful names, neat formatting, helpful comments—and it should avoid clever tricks and unusual constructions. Consistency is important because others will find it easier to read your code, and you theirs, if you all stick to the same style. Details may be imposed by local conventions, management edict, or a program, but even if not, it is best to obey a set of widely shared conventions. We follow the style used in the book *The C Programming Language*, with minor adjustments for C++ and Java.

We will often illustrate rules of style by small examples of bad and good programming, since the contrast between two ways of saying the same thing is instructive. These examples are not artificial. The "bad" ones are all adapted from real code, written by ordinary programmers (occasionally ourselves) working under the common pressures of too much work and too little time. Some will be distilled for brevity, but they will not be misrepresented. Then we will rewrite the bad excerpts to show how they could be improved. Since they are real code, however, they may exhibit multiple problems. Addressing every shortcoming would take us too far off topic, so some of the good examples will still harbor other, unremarked flaws.

To distinguish bad examples from good, throughout the book we will place question marks in the margins of questionable code, as in this real excerpt:

```
?    #define ONE 1
?    #define TEN 10
?    #define TWENTY 20
```

Why are these `#define`s questionable? Consider the modifications that will be necessary if an array of `TWENTY` elements must be made larger. At the very least, each name should be replaced by one that indicates the role of the specific value in the program:

```
#define INPUT_MODE 1
#define INPUT_BUFSIZE 10
#define OUTPUT_BUFSIZE 20
```

1.1 Names

What's in a name? A variable or function name labels an object and conveys information about its purpose. A name should be informative, concise, memorable, and pronounceable if possible. Much information comes from context and scope; the broader the scope of a variable, the more information should be conveyed by its name.

Use descriptive names for globals, short names for locals. Global variables, by definition, can crop up anywhere in a program, so they need names long enough and descriptive enough to remind the reader of their meaning. It's also helpful to include a brief comment with the declaration of each global:

```
int npending = 0;  // current length of input queue
```

Global functions, classes, and structures should also have descriptive names that suggest their role in a program.

By contrast, shorter names suffice for local variables; within a function, `n` may be sufficient, `npoints` is fine, and `numberOfPoints` is overkill.

Local variables used in conventional ways can have very short names. The use of `i` and `j` for loop indices, `p` and `q` for pointers, and `s` and `t` for strings is so frequent that there is little profit and perhaps some loss in longer names. Compare

```
for (theElementIndex = 0; theElementIndex < numberOfElements;
        theElementIndex++)
    elementArray[theElementIndex] = theElementIndex;
```

to

```
for (i = 0; i < nelems; i++)
    elem[i] = i;
```

Programmers are often encouraged to use long variable names regardless of context. That is a mistake: clarity is often achieved through brevity.

There are many naming conventions and local customs. Common ones include using names that begin or end with `p`, such as `nodep`, for pointers; initial capital letters for `Globals`; and all capitals for `CONSTANTS`. Some programming shops use more sweeping rules, such as notation to encode type and usage information in the variable, perhaps `pch` to mean a pointer to a character and `strTo` and `strFrom` to mean strings that will be written to and read from. As for the spelling of the names themselves, whether to use `npending` or `numPending` or `num_pending` is a matter of taste; specific rules are much less important than consistent adherence to a sensible convention.

Naming conventions make it easier to understand your own code, as well as code written by others. They also make it easier to invent new names as the code is being written. The longer the program, the more important is the choice of good, descriptive, systematic names.

Namespaces in C++ and packages in Java provide ways to manage the scope of names and help to keep meanings clear without unduly long names.

Be consistent. Give related things related names that show their relationship and highlight their difference.

Besides being much too long, the member names in this Java class are wildly inconsistent:

```
?   class UserQueue {
?       int noOfItemsInQ, frontOfTheQueue, queueCapacity;
?       public int noOfUsersInQueue() {...}
?   }
```

The word "queue" appears as Q, Queue and queue. But since queues can only be accessed from a variable of type UserQueue, member names do not need to mention "queue" at all; context suffices, so

```
?   queue.queueCapacity
```

is redundant. This version is better:

```
class UserQueue {
    int nitems, front, capacity;
    public int nusers() {...}
}
```

since it leads to statements like

```
queue.capacity++;
n = queue.nusers();
```

No clarity is lost. This example still needs work, however: "items" and "users" are the same thing, so only one term should be used for a single concept.

Use active names for functions. Function names should be based on active verbs, perhaps followed by nouns:

```
now = date.getTime();
putchar('\n');
```

Functions that return a boolean (true or false) value should be named so that the return value is unambiguous. Thus

```
?   if (checkoctal(c)) ...
```

does not indicate which value is true and which is false, while

```
if (isoctal(c)) ...
```

makes it clear that the function returns true if the argument is octal and false if not.

Be accurate. A name not only labels, it conveys information to the reader. A misleading name can result in mystifying bugs.

One of us wrote and distributed for years a macro called `isoctal` with this incorrect implementation: