Preface

"Consistently separating words by spaces became a general custom about the tenth century A.D., and lasted until about 1957, when FORTRAN 77 abandoned the practice."

(Fortran 77 4.0 Reference Manual, Sun Microsystems, Inc)

Since the beginning of the computing age, researchers have been developing numerical Earth system models. Such tools, which are now used for the study of climate dynamics on decadal- to multi-millennial timescales, provide a virtual laboratory for the numerical simulation of past, present, and future climate transitions and ecosystems. In a way, the models bridge the gap between theoretical science (where simplifications are necessary to make the equations tractable) and the experimental science (where the full complexity of nature manifests itself, as multiple phenomena often interact in nonlinear ways, to form the final signal measured by the apparatus). Models provide intermediate subdivisions between these two extremes, allowing the scientist to choose a level of detail that (ideally) strikes a balance between accuracy and computational effort.

The development of models has accelerated in the last 50 years, largely due to decreasing costs of computing hardware and emergence of programming languages accessible to the non-specialist. Fortran, in particular, was the first such language targeting scientists and engineers, therefore it is not surprising that many models were written using this technology. To many, however, this long history also causes Fortran to be associated with the punched cards of yesteryear and obsolete software practices (hence the quotation above). A programming language, however, evolves to meet the demands of its community, and such was also the case with Fortran: object-oriented and generic programming, a rich array language, standardized interoperability with the `C`-language, free-format (!), and many more features are now available to Fortran programmers who are willing to take notice.

Unfortunately, many of the newer features and software engineering practices that we consider important are only discussed in advanced books or in specialized reference documentation. We believe this unnecessarily limits (or delays) the exposure of beginning scientific programmers to tools, which were ultimately designed to make their work more manageable. This observation motivated us to write the present book, which provides a short "getting started" guide to modern Fortran, hopefully useful to newcomers to the field of numerical computing within *Earth system science* (ESS) (although we believe that the discussion and code examples can also be followed by practitioners from other fields). At the same time, we hope that readers familiar with other programming languages (or with earlier revisions of the Fortran-standard) will find here useful answers for the "How do I do X in modern Fortran?" types of questions.

Chapters Outline

In Chap. 1, we start with a brief history of Fortran, and succinctly describe the basic tools necessary for working with this book. In Chap. 2, we expose the fundamental elements of programming in Fortran (variables, I/O, flow-control constructs, the Fortran array language, and some useful intrinsic procedures). In Chap. 3, we discuss the two main approaches supported by modern Fortran for structuring code: *structured programming* (SP) and *object-oriented programming* (OOP). The latter in particular is a relative newcomer in the Fortran world.

The example-programs (of which there are many in the book) accompanying the first three chapters are intentionally simple (but hopefully still not completely uninteresting), to avoid obfuscating the basic language elements. After practicing with these, the reader should be well equipped to follow Chap. 4, where we illustrate how the techniques from the previous chapters may be used for writing more complex applications. Although restricted to elementary numerical methods, the case studies therein should resemble more of what can be encountered in actual ESS models.

Finally, in Chap. 5 we present additional techniques, which are especially relevant in ESS. Some of these (e.g., namelists, interoperability with `C`, interacting with the *operating system* (OS)) are Fortran features. Other topics (I/O with *NETwork Common Data Format* (`netCDF`), shared-memory parallelization, build systems, etc.) are outside the scope of the Fortran language-standard, but nonetheless essential to any Fortran programmer (the `netCDF` is ESS-specific).

Language-Standards Covered

The core of the book is based on Fortran 95.[1] Building upon this basis, we also introduce many newer additions (from Fortran 2003 and Fortran 2008[2]), which complete the discussion or are simply "too good to miss"—for example OOP,

[1] This was, at the time of writing, the most recent version with ubiquitous compiler support.

[2] Many compilers nowadays have complete or nearly complete support for these newer language-standard revisions.

interoperability with the C-language, OS integration, newer refinements to the Fortran array language, etc.

Disclaimers

- Given the wide range of topics covered and the aim to keep our text brief, it is obvious that we cannot claim to be comprehensive. Indeed, good monographs exist for many topics, which we only superficially mention (many further references are cited in this text).
- Finally, we often provide advice related to what we consider good software practices. This selection is, of course, subjective, and influenced by our background and experiences. Specific project conventions may require the reader to adapt/ignore some of our recommendations.

How to Use this Book

Being primarily a compact guide to modern Fortran for beginners, this book is intended to be read from start to finish. However, one cannot learn to program effectively in a new language just by reading a text—as in any other "craft", practice is the best way to improve. In programming, this implies reading and writing/testing as much code as possible. We hope the reader will start applying this philosophy while reading this book, by typing, compiling, and extending the code samples provided.[3]

Readers with programming experience may also use "random access," to select the topics that interest them most—the chapters are largely independent, with the exception of Chap. 5, where several techniques are demonstrated by extending examples from Chap. 4.

Due to the "breadth" of the book, many technical aspects are covered only superficially. To keep the main text brief, we opted to provide as footnotes suggestions for further exploration. Unfortunately, this led to a significant number of footnotes at times; the reader is encouraged to ignore these, at least during a first reading, if they prove to be a distraction.

[3] Nonetheless, the programs are also available for download from `SpringerLink`. The authors also provide a code repository on `GitHub`: assuming a working installation of the `git` version-control system is available, the code repository can be "cloned" with the command:

```
git clone https://github.com/dchirila/imf_ess.git
```

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