Toward Modern Fortran Tooling and a Thriving Developer Community

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Abstract

Fortran is the oldest high-level programming language that remains in use today and is one of the dominant languages used for compute-intensive scientific and engineering applications. However, Fortran has not kept up with the modern software development practices and tooling in the internet era. As a consequence, the Fortran developer experience has diminished. Specifically, lack of a rich general-purpose library ecosystem, modern tools for building and packaging Fortran libraries and applications, and online learning resources, has made it difficult for Fortran to attract and retain new users. To address this problem, an open source community has formed on GitHub in 2019 and began to work on the initial set of core tools: a standard library, a build system and package manager, and a community-curated website for Fortran. In this paper we report on the progress to date and outline the next steps.

1 Introduction

Fortran is the oldest high-level programming language that is still in active use and development today. Designed and implemented at IBM by Backus et al. (1957), it has evolved through about a dozen iterations, initially vendor-specific, and later as an international standard (ISO/IEC JTC 1/SC 22/WG 5 2018). Today, Fortran supports multiple programming paradigms, with strong emphasis on easy numerical calculations over large multi-dimensional arrays and on backward compatibility. Its Standards Committee keeps Fortran narrowly focused on the needs of scientific and engineering application developers. The language is natively parallel, allowing the programmer to express parallel algorithms—on shared and distributed memory systems alike—using the built-in language syntax and intrinsics, instead of external libraries like the Message Passing Interface (Gropp et al. 1996). Reid, Long, and Steidel (2020) documented the evolution of Fortran’s parallel features. Although these features have seen relatively slow implementation by the compiler vendors, applications that use native parallel features are becoming more common (e.g., Garain, Balsara, and Reid 2015; Mozdzynski, Hamrud, and Wedi 2015; Shterenlikht, Margetts, and Cebamanos 2018; Curcic 2019; Diaz et al. 2021). Today, Fortran remains the dominant language used on top High Performance Computing (HPC) systems, with applications to weather and climate (Powers et al. 2017; Skamarock, Ong, and Klemp 2021), computational chemistry (Čertík, Pask, and Vackář 2013; Apra et al. 2020), computational fluid dynamics (Sharma and Moulitsas 2017), life science (Aguilar 2021).
et al. 2018; Vandenplas et al. 2020), and economics (Harrison and Pearson 1996; Fehr and Kindermann 2018).

Fortran advances every several years through the revisions of its standard, Fortran 2018 being the latest. However, its tooling and library ecosystem have not benefited from the compounding effects of community building. We speculate that this is due to the lack of organization and communication between otherwise isolated groups of Fortran developers. As a consequence, the Fortran user experience has not improved to the level of other modern languages such as Python (Sanner et al. 1999), Go (Donovan and Kernighan 2015), or Rust (Klabnik and Nichols 2019). Specifically, general-purpose programming tools like algorithms, containers, and good string support, typically found in standard libraries of other languages, have been lacking. Fortran programmers often resorted to implementing these facilities in-house, thus reinventing the wheel at the cost of software quality and project budget. Further, there has been no single recommended build system for Fortran software, and most projects have been using Autotools, CMake, or custom build scripts. A novice Fortran programmer thus needs to spend significant amount of time learning and maintaining the build infrastructure instead of focusing on the application or library itself. Lack of a dedicated and user-friendly build system and package manager has not only hindered development, but also the distribution of the software. Improving the Fortran tooling and ecosystem of libraries is therefore essential for the long-term well-being of the language and its userbase.

In this article, we describe the motivation and goals of the new open source community, Fortran-lang, and report on the progress made so far. We describe its three key software projects: Fortran Standard Library (stdlib), Fortran Package Manager (fpm), and the new Fortran website and related communication channels. A birds-eye view of each project, their elements and themes, and how they integrate within the community is shown on Figure 1. Each of the projects we describe in more detail in the following sections. We also describe the Fortran proposals incubator repository, in which the Fortran-lang efforts were first conceived. We briefly present LFortran, a modern interactive open source compiler that will eventually integrate with other Fortran-lang projects. Finally, we provide a brief outlook on the near-future development for each of the projects.

2 Standard Library

2.1 Motivation

Unlike C or C++, The Fortran standard does not define a standard library. Instead, it defines a number of intrinsic (built-in) modules, procedures, and derived types (collectively called *intrinsics*). Some intrinsics are accessible through their respective intrinsic modules (e.g. *iso_fortran_env*), and others are available from the global namespace. Fortran 2018 defines 168 intrinsic procedures, and a smaller number of intrinsic constants and derived types. However, the intrinsic set is limited in scope, and does not include general algorithms, containers, and higher-level functionality commonly found in standard libraries of languages like C++ (Stroustrup 2013), Python, and Rust. Further, limitations in the design of strings and I/O facilities make it awkward to carry out common tasks like loading a CSV file with an unknown number of columns. While not impossible to do in Fortran, such tasks are trivial to do in many other programming languages. The lack of a standard library in Fortran thus significantly limits its ease of use, especially for newcomers to the language.

In late 2019, it became apparent that many user-requested functionalities could be implemented as a library, without needing to modify the language itself. Such functionalities have
Figure 1: A diagram of the Fortran-lang community and its projects.
been commonly implemented “in-house” by developers, leading to duplication of effort and higher risk of programming errors. Considering that a significant fraction of Fortran application development is funded by research grants, such duplication of effort directly incurs a significant financial cost, and delays the completion of the application. The traditional process of design and approval by committee, implementation by compilers, and finally, delivery to end-users is long—often taking more than 10 years. Instead, these features can be implemented early in a community-curated open source library. An obvious benefit of this approach, besides early delivery, is the opportunity to test and discover flaws in the design of a feature before it is standardized. A Fortran Standard Library (stdlib), designed and developed together by the end-user community and the Standards Committee, would help mitigate the above-mentioned problems.

2.2 Scope of stdlib

The Fortran Standard Library aims to provide a broad set of procedures, derived types, and constants for science, engineering, mathematics, and general-purpose programming. The science, engineering, and mathematics scopes are similar to those of Python libraries SciPy (Virtanen et al. 2020) and NumPy (Harris et al. 2020). The general-purpose scope covers strings, I/O, bitsets, logging, sorting, containers, and similar.

As a concrete motivation, consider the deferred-length string that was introduced in the Fortran 2003 standard. It is a welcome addition to the language and has a long history (e.g. L. Schonfelder (1991); J. L. Schonfelder (1996)). While this makes life easier for Fortran programmers, a drawback is that it is not possible to create an array of strings where each element has its own length, independent of the other elements, without also having to implement convenience routines. Addressing this shortcoming of built-in Fortran strings is one of the goals of stdlib.

2.3 A tour of stdlib

As of September 2021, stdlib implements a total of 17 modules:

- **stdlib.ascii**: This module provides character classification and conversion functions for ASCII characters and strings. Programmers experienced with C will recognize these functions as providing the equivalent functionality as those in the `ctype.h` header of the standard C library (Plauger 1992). The classification functions allow to determine membership of characters in different classes: letters (lower-case or upper-case), digits, blank characters, punctuation characters, control characters (such as newline, tab, and carriage return), and more. Each classification function accepts a single character as input and returns a scalar logical value. The functions return `.true.` if the dummy argument `c` satisfies the condition described, and `.false.` if not. The functions available are:
  - `is_alpha(c)` - `is_upper(c)` or `is_lower(c)` is true
  - `is_alphanum(c)` - `is_alpha(c)` or `is_digit(c)` is true
  - `is_ascii(c)` - ASCII character
  - `is_blank(c)` - space, tab
  - `is_control(c)` - control character
  - `is_digit(c)` - decimal digit
  - `is_graph(c)` - printing character except space
- is_hex_digit(c) - hexadecimal digit
- is_lower(c) - lower-case letter
- is_octal_digit(c) - octal digit
- is_printable(c) - printing character including space
- is_punctuation(c) - printing character except space or letter or digit
- is_upper(c) - upper-case letter
- is_white(c) - space, form feed, carriage return, newline, tab, vertical tab

For the seven-bit ASCII character set, the printing characters are achar(32) to achar(126); the control characters are achar(0) (NUL) to achar(31) (US), and achar(127) (DEL), where achar(i) is the Fortran intrinsic function that returns the character at position i in the ASCII collating sequence. For the remaining 8-bit character codes not in the ASCII set, the function return value is .false.. Character constants for the ASCII control characters are also available in the module (e.g. NUL, LF, TAB, and others). So are common character sequences such as lower-case and upper-case letters, digits (octal, decimal, and hexadecimal), as well as whitespace characters. These sequences are often used as the set argument of the intrinsic functions verify and scan. Finally, three functions are provided to convert character sequences between different cases:

- to_lower(str) - convert to lower-case
- to_upper(str) - convert to upper-case
- to_title(str) - capitalize first letter of each word

The lower- and upper-case functions are helpful to perform case-insensitive comparisons of character sequences and are requested by Fortran programmers time and again.

- stdlib_bitsets: This module offers two bitset types (bitset_64 and bitset_large), methods for bitset initialization and output, unary bitset methods and binary bit manipulation procedures. A bitset can be seen as a memory-efficient representation of a rank-one array of logical values, where each element occupies only one bit. While the functionality of the bitset_64 type is in a way similar to that of the intrinsic bit manipulation procedures using integer arguments as bit sequences, the bitset_large type is also capable of holding bitsets much larger than the standard integral types. Bitsets are often used to represent a subset of a finite set of elements. The bitwise and and bitwise or operators correspond to the set operations intersection and union, while the complement of the set can be found using the logical not operator. The following example program demonstrates creating and printing a bitset:

program bitset_demo
  use stdlib_bitsets, only: bitset_64
  implicit none

  integer, parameter :: BITSZ = 5
  type(bitset_64) :: bitvec
  character(len=::), allocatable :: bitstr
  integer :: i, cnt

  call bitvec%init(BITSZ) ! all zeros by default
call bitvec%set(0)
call bitvec%set(3)
call bitvec%set(4)

call bitvec%to_string(bitstr)
write(*,'(A)') bitstr ! prints '11001'
write(*,'(*(I1))') (bitvec%value(i), i = 0, BITSZ-1) ! prints '10011'

end program

Bits are enumerated from the least-significant bit at 0 to the most significant-bit at BITSZ - 1. Written from left to right, the bitset string goes from most-significant to least-significant bit.

• stdlib_error: This module currently provides functions check and error_stop.

• stdlib_io: This module provides high-level convenience wrapper functions to open and close statements. It also provides the functions loadtxt and savetxt that allow easy reading and writing of 2-dimensional arrays to and from text files, like the functions of the same name in the Python NumPy library.

• stdlib_kinds: This module provides a set of constants that define integer and real type kinds.

• stdlib_linalg: This module provides four functions for working with matrices: diag creates a diagonal array or extracts the diagonal elements from an array; eye returns a 2-dimensional identity matrix of arbitrary shape; outer_product computes the outer product of two vectors and returns a 2-dimensional matrix; and trace computes the trace of an input matrix.

• stdlib_logger: This module provides a single derived type logger_type that allows the user to emit messages to standard streams or files on disk, of various kinds (debug, informational, warning, or error). The module also provides a global instance of the logger_type for convenience. Here is an example of its use to report an error from an allocate statement:

module alloc_mod
    use stdlib_logger, only: logger_type
    implicit none

    type(logger_type) :: logger

    contains

    subroutine alloc_check(a, size)
        integer, allocatable, intent(in out) :: a(:)
        integer, intent(in) :: size
        integer :: stat
    end subroutine alloc_check
character(128) :: errmsg, message
allocate(a(size), stat=stat, errmsg=errmsg)
if (stat /= 0) then
  write( message, '("Allocation of a failed with size = ", i0)') size
  call logger % log_error(message, &
    module='example_mod', &
    procedure='example_sub', &
    stat=stat,  &
    errmsg=errmsg)
end if
end subroutine alloc_check

end module alloc_mod

• stdlib_math: This module will provide commonly used mathematical functions. Currently implemented are the arange, clip, linspace, and logspace functions. clip limits an input value to a given range:

res = clip(1.22, 0., 1.) ! returns 1.
res = clip(-0.5, 0., 1.) ! returns 0.
res = clip(0.75, 0., 1.) ! returns 0.75

Functions arange, linspace, and logspace return sequences of evenly spaced numbers on linear or logarithmic scales, similar to their namesakes in NumPy.

• stdlib_optval: Provides a convenience function optval to handle missing optional dummy arguments. For example, consider a function that increments an input value by 1 by default, and by increment incr if provided:

pure integer function increment(n, incr)
  integer, intent(in) :: n
  integer, intent(in), optional :: incr
  if (present(incr)) then
    increment = n + incr
  else
    increment = n + 1
  end if
end function increment

With optval, this can be written as:

pure integer function increment(n, incr)
  use stdlib_optval, only: optval
  integer, intent(in) :: n
  integer, intent(in), optional :: incr
  increment = n + optval(incr, 1)
end function increment

optval thus serves as syntactic sugar for easier handling of optional dummy arguments, until their handling is improved on the language level.
• stdlib_quadrature: This module provides different functions to integrate sampled values and weights for given abscissas using different approaches. Currently implemented are the functions to integrate using the Simpsons or trapezoidal rule.

• stdlib_sorting: This module provides efficient subroutines to sort arrays of intrinsic numeric and character types, as well as the string_type from the stdlib_string_type module.

• stdlib_stats: This module provides functions to compute descriptive statistics from elements of integer and real arrays up to rank 15. Currently are implemented functions to compute Pearson correlations (corr), covariances (cov), means (mean), various central moments (moment), and variances (variance). Descriptive statistics can be computed along a specified dimension, and/or following a provided mask.

• stdlib_stats_distribution_PRNG: This module will provide pseudo-random number generators for various statistical distributions. Currently implemented are only functions to generate pseudo-random integers. Several other distributions are currently under review.

• stdlib_string_type: This module contains a non-extendible derived type representing a character sequence, string_type. It addresses major shortcomings of deferred length character variables, like the use in an elemental context, creating arrays of strings with non-uniform length, and memory safety in accessing the character value. Values of string_type can be created by assignment of fixed length character values or by invoking the string_type constructor from fixed and deferred length character values as well as integer and logical values.

type(string_type) :: str
str = "literal" ! string contains value "literal"
str = string_type() ! empty string
str = string_type("literal") ! string contains value "literal"
str = string_type(42) ! string contains value "42"
str = string_type(.true.) ! string contains value "T"

All string-related intrinsic functions and operators are overloaded by this module to provide seamless integration with the existing use of deferred length character variables. Most of the overloaded functions are available as elemental to allow easy use for array-oriented programming. For example, scanning for the existence of a character set on a list of strings works naturally:

program string_type_demo
  use stdlib_string_type
  implicit none
  type(string_type), allocatable :: list(:)

  list = [string_type("fortran"), string_type("c"), string_type("python")]

  print *, scan(list, "ao") ! returns [2, 0, 5]
  print *, scan(list, "ao", back=.true.) ! returns [6, 0, 5]
end program string_type_demo
Furthermore, user defined derived type input and output functionality is provided. Repetitive tasks like reading a whole line into a deferred length character variable become as simple as

```fortran
  type(string_type) :: line
  read(unit, *) line
```

The `string_type` is the basic building block to further develop string processing in stdlib.

- **stdlib.stringlist_type**: This module provides a derived type that is a container for strings of varying length. Its main component is an allocatable array of `string_type` instances, with methods to efficiently get and insert elements at arbitrary positions.

- **stdlib.strings**: This module provides procedures for string processing. The lack of string processing facilities has been one of the initial motivations behind stdlib.

With numerical computations being the bread and butter of Fortran programmers, string processing has had a supporting role in contrast to other programming languages. Yet this has not stopped previous generations of Fortran programmers to develop useful tools including interpreters (e.g., MATLAB), lexical analyzers, virtual machines, macro processors, and even a simple programming language (Jones and Crabtree 1988). While repeating such “stunts” might be a pointless exercise with the powerful programming languages available today, they remain a testament that Fortran can be pushed further than what many think is possible.

The (in)capacity of Fortran string processing facilities has been recognized previously by Jones and Crabtree (1988): “Fortran is often maligned for its lack of facilities for character-oriented processing. ... The apparent deficiency of Fortran for string manipulation is primarily because of the methods traditionally used rather than because of a shortcoming of the language itself. The main shortcoming of Fortran for string handling is the lack of a standard library of routines for often-needed functions. As Fortran programmers we are faced with a choice: we either invest the up-front effort required to create our own standard library or we live with the continuing effort of hacking together a solution each time we are presented with similar problems.”

Compared to numerical applications, which have been traditionally covered by vendor libraries (NAG, IMSL, HSL, MKL), string handling libraries are typically small, single-user driven, and dispersed.

To address these deficiencies, the `stdlib.string` module provides the following functions:

- `chomp` - remove trailing characters, given an input set or substring of characters to remove;
- `count` - count the number of substring patterns in a string;
- `find` - return an n-th occurrence of a substring pattern in a given string;
- `padl` and `padr` - left- and right-pad a string with an input character;
- `reverse` - reverse a string;
- `slice` - extract characters from a defined region of the input string by taking strides;
- `starts_with` and `ends_width` - test that the string begins or ends with a substring;
- `strip` - remove all whitespace characters;
- `to_string` - convert an intrinsic numeric or logical scalar value into a string, given an input format string (edit descriptor).
String facilities that remain to be implemented include subroutines for splitting and joining strings, pattern matching and substitution, tokenization and parsing, dynamic string lists, transformations (padding, removing spaces or other trailing characters), remaining character to numeric conversion routines and vice versa, among others.

• **stdlib_system**: This module will contain procedures for portable system programming on different platforms. Many programs need to get information about what is going on outside, and act upon this information inside of the program. Apart from the intrinsic `read` and `write` statements, standard Fortran provides limited support to execute system commands, retrieve command-line arguments, inspect environment variables, and interact with the file system. To fill this void, compiler vendors currently provide their own extension modules (e.g. the Intel `ifport` module, or NAG’s `f90_unix_*` modules) or offer (non-standard) built-in procedures to C system functions. Plans for the `stdlib_system` module include procedures to retrieve information about the system (operating system, platform endianness) and user (group), list and manage files, directories, and their attributes, interact with terminal emulators, spawn and control subprocesses, and handle signals and program control, among others.

Many of these goals can be achieved by interfacing to the respective system libraries using the standard C interoperability features. So far, the `stdlib_system` module only offers a cross-platform version of the subroutine `sleep(millisec)` which causes the calling thread to sleep for an integer amount of milliseconds. Efforts are under way to provide basic file system operations, such as creating and removing directories, renaming files, and manipulating file paths.

The Fortran stdlib API documentation (https://stdlib.fortran-lang.org) is generated by FORD (MacMackin 2018).

### 2.4 Auto-generation of specific procedures

A significant limitation of generic programming in Fortran is that one needs to implement many specific procedures that are to be invoked using a generic name. Consider for example a function `mean(x)` which returns the arithmetic average of all elements of an input array `x`. Implementing a generic function `mean(x)` that operates on integer or real arrays of any standard type kind (four for integers and three for reals), and of any rank (1 through 15), requires writing 105 specific procedures. To efficiently generate specific procedures for any number of types, type kinds, and ranks, we use the Python-powered preprocessor for Fortran, Fypp (Aradi 2020). For example, the following listing shows the meta-code that defines the `mean` function to be processed by Fypp:

```fortran
#:for k1, t1 in RC_KINDS_TYPES
  #:for rank in RANKS
    #:set RName = rname("mean_all",rank, t1, k1)
    module function ${RName} (x) result(res)
      ${t1}, intent(in) :: x${ranksuffix(rank)}$
      ${t1} :: res
      res = sum(x) / real(size(x, kind = int64), ${k1})
    end function ${RName}
```
where the RC_KINDS_TYPES and RANKS variables are defined elsewhere to specify which types, type kinds, and ranks will be used to generate the Fortran code.

2.5 Supported platforms

To build the Fortran Standard Library, the following tools are required:

- at least a Fortran 2008 compliant compiler;
- CMake version 3.14 or newer. Alternatively Make can be used;
- the Python-powered preprocessor Fypp.

Using the Continuous Integration and Deployment (CI/CD) pipeline provided by GitHub, all functions are tested at each merge of a pull request using various compilers on various operating systems. Specifically, stdlib is currently tested with GCC Fortran versions 9 to 11 on Ubuntu 18.04, macOS Catalina 10.15, and Windows Server 2019, and with Intel OneAPI 2021.1 on Ubuntu 20.04 and macOS Catalina 10.15. In addition to the compilers and OSs regularly tested by the CI/CD pipeline of stdlib, a list of compilers and operating systems tested by stdlib's users can be found on the GitHub README page of stdlib.

3 Fortran Package Manager

Among the biggest challenges that Fortran programmers deal with is building packages, reusing them as dependencies in other packages, and distributing them to other users. Until recently, Fortran programmers resorted to building their packages using Autotools, CMake, hand-written Makefiles, and even custom shell scripts. The latter approach is especially common to large community applications that are intended to build and run on many OSs and compiler vendors—a typical example being the Weather Research and Forecasting model (WRF, Powers et al. (2017)).

The problem with current approaches is the lack of a well established, recommended way to set them up so that multiple libraries work well together. Developers resort to custom and ad hoc workarounds to get the build systems of different libraries to work together in their project. They often find that it is not worth the effort, and rewrite the build system to fit the need of their project. This leads to duplicated effort and yet another solution that is not reusable in other projects.

The Fortran Package Manager (fpm) is designed as a Fortran-specific—rather than language agnostic—build system and package manager. Its key goal is to improve the user experience by making the development, reuse, and distribution of Fortran libraries and applications seamless and easy. Fpm is largely modeled after Rust’s Cargo, and takes inspiration from Haskell’s Stack, Node.js npm, and others. Using and managing dependencies with these systems often require no more than a single line in a project’s configuration file. Fpm assumes a default layout of the package to enable automatic discovery of module and program source files. A project that follows the fpm convention can thus be built just using the command fpm build, with minimal configuration necessary. By making the building and packaging as easy as possible for developers, fpm’s long term vision is to lower the bar for development and distribution of packages, and thus nurture and grow the ecosystem of modern Fortran applications and libraries.
Fpm is written in modern Fortran, and is an fpm package itself—given a binary executable of fpm, developers can use it to bootstrap fpm from source. An initial prototype was written in Haskell in the Spring of 2020. Its goal was to quickly prototype and test the initial design of the system. It implemented sufficient functionality to allow other open-source Fortran developers to adopt fpm’s packaging system, provide feedback, and even contribute back to fpm. By the Summer of 2020 we became confident that the initial design of fpm was likely to work, as seen from the adoption and feedback during the prototype phase, when Fortran developers began adopting fpm’s packaging conventions in their own projects. We began working on the production implementation of fpm in Fortran, bringing two major boons to the project. First, a large community of Fortran developers began contributing to fpm immediately. Second, fpm helped motivate the development of auxiliary tools—such as strings and file system operations—that are sorely lacking from the Fortran ecosystem. A Fortran implementation of fpm thus helps feed back to the Standard Library and the broader ecosystem of libraries. As more 3rd-party libraries and applications adopt the fpm convention, its value grows thanks to the network effects—the more libraries there are to use as dependencies, the easier it becomes to start and rapidly prototype a new project.

3.1 A short demo of fpm

Using fpm should feel natural to anyone familiar with command line operations, especially POSIX compliant tools. Executing the command fpm with no arguments, or with the -h or --help options, provides a summary of its options, as illustrated below.

$ fpm
Fortran Package Manager:

USAGE: fpm [ SUBCOMMAND [SUBCOMMAND_OPTIONS] ]|[--list|--help|--version]
where SUBCOMMAND is commonly new|build|run|test

subcommand may be one of

build Compile the package placing results in the "build" directory
help Display help
list Display this list of subcommand descriptions
new Create a new Fortran package directory with sample files
run Run the local package application programs
test Run the test programs
update Update and manage project dependencies
install Install project

Enter "fpm --list" for a brief list of subcommand options. Enter "fpm --help" or "fpm SUBCOMMAND --help" for detailed descriptions.

Using the -h or --help options with a subcommand provides additional details about the options that it supports. For example, executing the command fpm build --help reports the following information:

$ fpm build --help
NAME
build(1) - the fpm(1) subcommand to build a project

SYNOPSIS
fpm build [--profile PROF] [--flag FFLAGS] [--compiler COMPILER_NAME] [-list]

fpm build --help|--version

DESCRIPTION
The "fpm build" command
  o Fetches any dependencies
  o Scans your sources
  o Builds them in the proper order

The Fortran source files are assumed by default to be in
  o src/     for modules and procedure source
  o app/     main program(s) for applications
  o test/    main program(s) and support files for project tests
              o example/ main program(s) for example programs

Changed or new files found are rebuilt. The results are placed in
the build/ directory.

Non-default pathnames and remote dependencies are used if
specified in the "fpm.toml" file.

OPTIONS
--profile PROF  selects the compilation profile for the build.
                Currently available profiles are "release" for
                high optimization and "debug" for full debug options.
                If --flag is not specified the "debug" flags are the
                default.

--flag FFLAGS    selects compile arguments for the build. These are
                  added to the profile options if --profile is specified,
                  else these options override the defaults.
                  Note object and .mod directory locations are always
                  built in.

--compiler COMPILER_NAME  Specify a compiler name. The default is
                            "gfortran" unless set by the environment
                            variable FPM_COMPILER.

--list  list candidates instead of building or running them

--show-model show the model and exit (do not build)

--help  print this help and exit

--version print program version information and exit

EXAMPLES
Sample commands:

  fpm build        # build with debug options
  fpm build --profile release # build with high optimization
The simplest and most common use of fpm involves performing a process like the following:

1. Execute `fpm new` to create a new project.
2. Make edits to existing files, and/or create new files in the app, src, and/or test directories.
3. Execute `fpm test` and/or `fpm run` to ensure that the code compiles and executes as expected.
4. Edit the `fpm.toml` file to add new dependencies.
5. Publish your project to a repository hosting service such as GitLab, GitHub, or any other publicly accessible git server.
6. Notify the maintainers of the fpm registry of your new package, to allow other users to easily find and use your project.

The primary venue to interact with a Fortran project is the command line interface of fpm. All common tasks are available via subcommands that provide reasonable default choices and that can be customized using flags and/or manifest settings.

### 3.2 Currently supported functionality

By default, fpm assumes a specific directory layout for the source files to be placed in. It automatically finds library sources in the src directory, applications in the app directory, and unit tests in the test directory. However, the default behavior can be overridden by editing the package manifest—a configuration file in TOML format that resides in the root directory of the project. TOML is a widely used configuration language that helps minimize the burden on the programmer to write build files. Fpm also allows creating a new, skeleton project via the command `fpm new`. One can build, run, and test a project using the commands `fpm build`, `fpm run`, and `fpm test`, respectively. It is also possible to install a project via `fpm install`, which performs the build step if necessary, and makes the project executables available in user’s path.

Internally, fpm builds a detailed model of a Fortran package and its dependencies by scanning the source files found in default locations and processing the information provided in a package manifest file and at the command line. This internal model captures the types of Fortran sources that are present, their module/submodule interdependencies, and in which order to invoke the compiler to successfully build the project. Fpm can thus compile large, complex projects that consist of both Fortran and C sources, automatically and in parallel where possible. It contains recommended default sets of compiler flags for debug and release profiles across several commonly available Fortran compilers. This is particularly helpful when working with multiple compilers and different profiles, where fpm automatically separates build outputs and performs incremental re-compilation when necessary.

Fpm’s role as a package manager is perhaps the most innovative aspect, allowing Fortran developers to effortlessly incorporate third-party Fortran packages in their own project. It currently supports a decentralized distribution environment in which project dependencies are specified as remote git repositories in the project manifest file. Versioning of project dependencies can be pinned in a straightforward manner by specifying a commit or tag. Specifying a dependency in the fpm manifest file requires a single entry, for example:

```toml
[dependencies]
toml-f = { git = "https://github.com/toml-f/toml-f", tag = "v0.2.1" }
```
Once added to the manifest, fpm will fetch the remote dependency and incorporate its library sources into the internal model such that its modules and procedures can be imported as if they were within the current package. Likewise, publishing an fpm package as a public git repository makes it immediately available as a dependency for use in any other fpm package.

Users can customize various aspects of fpm behavior, for example:

- Specify the compiler and compiler options via command line flags
- Use external module dependencies (such as MPI, NetCDF (Rew and Davis 1990), and similar) by specifying paths on the command line
- Specify non-default locations for main programs via the manifest (fpm.toml)
- Specify external libraries, such as BLAS or LAPACK, to be linked via the manifest

The fpm registry currently lists 32 Fortran packages that can be automatically downloaded, compiled, and imported in user code using fpm’s dependency feature.

### 3.3 Future functionality

While the core functionality of fpm is complete and is gaining traction with users, many other features are planned for future development:

- Generating configuration files for other build systems like Make, CMake, Conda, and others
- Searching for packages in the central fpm package registry
- Better support to specify compiler options
- A plug-in architecture to allow easy development of new capabilities as separate packages
- Standardized support for preprocessors
- Better support for external dependencies, such as MPI, NetCDF, and other common dependencies

Suggestions for others are always welcome and can be submitted at [https://github.com/fortran-lang/fpm/issues](https://github.com/fortran-lang/fpm/issues).

### 4 Fortran proposals incubator repository

Fortran-lang efforts stemmed from the Fortran proposals repository that we created in October 2019 with the aim to allow anybody to easily discuss new ideas for the Fortran Standards Committee. Quickly the wide Fortran community started providing feedback and the repository also served as a way to organize our initial community. After Fortran-lang was created, the community organized around it, and the proposals repository is now used specifically to suggest changes to the language itself.

This repository has been successful and we hope that the community will use it to provide feedback to the Committee and participate more in the standardization process. To date, 14 members of the Fortran Standards Committee have participated in the discussions, and 180 proposals have been initiated by the community. Many of these proposals motivated the creation of the Fortran Standard Library. Several others, such as adding support for modules as namespaces, setting default values for optional dummy arguments, and improving the API of the Fortran 202X split intrinsic, have been refined and presented at the committee meetings. The split intrinsic proposal has been voted on by the Committee and resulted in the changes
Another evidence of success is the tighter integration of the community with the Standards Committee. To date, two new members (Richardson and Curcic) have joined J3 (PL22.3, the US body of the Standards Committee) as the direct result of their participation with the proposals repository and engaging with the Committee. The level of participation from end-users, the number of proposals submitted, and the new members that joined the Committee all serve as a record of success of this GitHub repository.

5 LFortran

Another element that has sorely been missing from the Fortran ecosystem is an interpreter that would allow interactive development for rapid prototyping. LFortran is a modern open-source (BSD licensed) interactive Fortran compiler built on top of LLVM. It can execute user’s code interactively to allow exploratory work (like Python, MATLAB, or Julia) as well as compile to binaries to run user’s code on modern architectures such as multi-core CPUs and GPUs.

The initial prototype was written in Python and was successfully shown to work interactively in a Jupyter notebook. After the public announcement, it received positive response from the community.

Since then, we have rewritten it in C++ for speed and robustness. It has several backends:

- The LLVM backend is used to compile to binaries as well as interactive use in Jupyter or a command line REPL
- The C++ backend can translate Fortran code into readable C++
- The x86 backend can generate x86 machine code directly which allows fast compilation.

As of September 2021, the parser can parse all of Fortran 2018 syntax, and the compiler can compile simple projects to binaries. These features also work interactively. We are working toward releasing a Minimum Viable Product (MVP) that compiles several third-party projects that use most of Fortran 95 features.

After releasing the MVP, we will implement all Fortran 2018 features, add more backends, and use LFortran as an infrastructure for other Fortran tools, such as automatic formatters, documentation generators, automatic wrappers to other languages (Python, C++, Julia, etc.), language servers for code editors (VSCode, Vim, Emacs), etc. We also plan to use the Jupyter notebooks powered by the LFortran kernel to create interactive tutorials for Fortran, hosted at fortran-lang.org.

6 fortran-lang.org

In April 2020, another software project was started under the Fortran-lang umbrella: A community-curated website to serve as the home of Fortran on the internet (Figure 2).

The website, located at https://fortran-lang.org, consists of five components:

1. A Learning page that includes community-curated tutorials (mini-books), links to other Fortran resources on the internet, and an extensive list of Fortran books and free Fortran courses. The community-curated mini-books currently include a “quick-start” Fortran tutorial, a tutorial on building programs, and a tutorial on setting up a Fortran development environment. To help improve Fortran user acquisition, these tutorials are especially geared toward newcomers to the language.
2. A Compilers page that lists all Fortran compilers that are currently active, commercial and open source alike.

3. A Community page that provides links and activity from the Fortran-lang projects as well as attributing all GitHub contributors to the Fortran-lang project repositories.

4. A Package index that provides a community-curated list of, and a search bar for, Fortran libraries and applications, tagged by category. Anybody can submit a package for inclusion in the index, however, there are quality criteria that a package must satisfy, such as to have an open source license, to have user documentation, and that its core functionality is fully implemented.

5. A monthly newsletter in which we report on the progress at the beginning of each month.

The website is entirely open source, hosted at https://github.com/fortran-lang/fortran-lang.org/, and we welcome contributions from the community. Most website content is written in the easy-to-learn Markdown language and the structure is set up such that adding new content like tutorials is straightforward.

While we do not know the number of visitors to the website due to the absence of web user trackers, there are at least two signs of early success of the website. First, the search engine rankings have been steadily improving during the past year. As of April 2021, the rank of the result being https://fortran-lang.org given the search term “fortran”, while in private-browsing mode, is #2 for Google, and #1 for Bing, DuckDuckGo, and SearchEncrypt search engines. Second, the Fortran page on Wikipedia has been edited by their moderators to include a URL to the Fortran-lang website. Both the search engine rankings and the listing on Wikipedia are important because they expand the surface area over which new users can discover and learn more about Fortran, thus helping to ensure Fortran’s long term well being.

In addition to the main website, another new and dynamic web presence for Fortran comes in the form of a modern web forum for discussing all things Fortran: https://fortran-lang.discourse.group. The forum is run on the popular Discourse platform which is used by many programming language communities thanks to its many invaluable features, including: easy
Markdown formatting of posts, including code blocks; categorization of threads; user tagging; direct messages; and post moderation. The Fortran Discourse has quickly grown to nearly 300 registered users during its first year, and now averages around 4000 page views per day and 200 new posts per week (Figure 3). Importantly, the Discourse aims to be an open and welcoming community for all, beginners and experts alike, through which users may seek help, share knowledge, and keep up-to-date with Fortran-lang projects and events. Similarly, a new mailing list (fortran-lang@groups.io) and Twitter account (@fortranlang) are also provided as a low-bandwidth alternative for users who wish to be kept informed of Fortran-lang activity and news more directly.

A successful step toward bringing-together the Fortran community has been the organization of monthly video calls which are open to all and advertised via the Discourse, mailing list, and Twitter account. These meetings allow real-time discussion on the various Fortran-lang projects presented herein and are particularly beneficial in pushing forward important decisions with advice and support from the wider community.

### 7 Summary

A new open source community called Fortran-lang was formed to address the lack of modern Fortran tooling such as a comprehensive standard library, a dedicated build system and package manager, and an interactive compiler. Since December 2019, it has attracted code contributions from over 60 participants across several projects. Fortran-lang’s key projects are the Fortran Standard Library (stdlib), Fortran Package Manager (fpm), and the Fortran website and associated online platforms. The standard library aims to provide the most common tools a programmer may need in their daily work, akin to standard libraries of other programming languages. It currently provides 11 modules with utilities from math and statistics to strings and I/O. Fpm is both a build system and a package manager, with the main goal to improve user experience. To date, the key functionalities have been implemented—creating a new Fortran project, building the library, and building and running the tests and executables. Fpm also automatically fetches and builds fpm-enabled dependencies, allowing the program-
mer to focus on their library or application development. LFortran is a modern and interactive open source compiler that will eventually integrate with other Fortran-lang projects. Finally, the Fortran website provides community-curated tutorials, compiler resources, and a Fortran package index. The website, and its associated Discourse forum, mailing list, and newsletter aim to bring Fortran programmers from around the world together in a friendly, inclusive, and moderated setting. Together with the Standard Committees’ efforts, we hope that these projects will serve as a foundation for a stronger, richer, and more accessible Fortran for the 21st century.

Acknowledgements. We thank all open source contributors who worked hard across all Fortran-lang projects: Aaron Graham, Aaron Meurer, acferrad, Adam Denchfield, Aditya Shukla, Adriano Amaricci, Agustin Forero, Abhi Olasunkanni Matthew, Alexis Perry-Holby, Alfo Lazzaro, Alin Marin Elenna, Aman Godara, Amir Shahmoradi, Amit Kumar, Anar Yusifov, Andre Mikulec, Andre Smit, andrew_4619, Andy Malcolm, Aniruddha Das, Ankit Pandey, Antoine Levitt, Arijit Banerjee, Armin Wehrfritz, Artu Rässänen, arunningcroc, Asdrubal Lozada-Blanco, ashe, Ashish Panigrahi, Ashok Jamm, Ashutosh Pandey, Ashwin Vishnu, Atias, Avinash Vijayvargiya, Bálint Aradi, Beliavsky, Bharat Mahajan, Bhuvenesh Vashishat, Bill Long, Bishal Das, bitbag, Bob Apthorpe, Bojan Niceno, Brian Callahan, Brian Cornille, Bryce Adelstein Lelbach, bwe, Carl Burkert, Carlos Une, catulus, C’Conde, Chetan Karwa, Chris Elrod, Chris MacMackin, Clive Page, Conor Hoekstra, cradoest, CYehLu, Cyrille Lavigne, Damian Rouson, dannytoearth, Dauptain, dav05, David Bentlage, David Duffy, David Lauvergnat, David McParland, David Meyer, David Navia, David Spurr, Deepak Kumar, Dhiganth Rao, difference-scheme, Dmitrii Pasechnik, Dobrodzieju, Dominic Poerio, Dominik Gronkiewicz, D. Sundar Chand, E. D. Bakker, Edger Sterjo, Elias Rabel, Emanuele Pagone, Emilio, Eugene Epshteyn, Euler-37, Evan Voyles, Ev. Drikos, Evert Provoost, Fábio Malacca Moreira, Fabio Souto de Azevedo, Fernando Oleo Blanco, Fernando Pérez, Filippo M., Fran, Gabriel Brown, Gaggandeep Singh, Gareth Davies, Gary Klimowicz, Gary Styer, Gilles Gouaillardet, Greg Hamblin, haixingwuy, Hank, Han Tang, haomiao, haraldkl, Harper, Harris Snyder, Harsh Bardhan Mishra, Herve Wozniak, Himanshu Pandey, Hongyi Zhao, hpigula, Hugo Nava Ramos, H. Vetinari, Ian Allison, Ian Bush, Ian Chivers, Ian Giestas Pauly, Ignacio López de Arbina, implicitall, Ivrise, Ivan Morozov, Izaak "Zaak" Beekman, Jacob Marks, Jacob Williams, Jakub Jelinek, Jamie, Jane Sleightholme, Jason Blevins, Jason H. Nicholson, Jason Miller, jbdv, Jeff Armstrong, Jeff Hammond, Jellby, Jerry Delisle, Jim Fisher, Joe Schoonover, Johannes Gebert, Johannes_R, Johann Weber, John Alexiou, John Collins, John Siegrist, John Urban, Jonny, Jordan John, José Mª Escartín, Joseph Schoonover, Juan, Juan Fiol, Julian Henneberg, Jürgen Reuter, junnix, Justin Dedewaranou, Kai Gao, Karan Kapoor, Karl (rcs), Katherine Holcomb, Ketan Patil, Kiran Chandramohan, Kjell Jonrer, Laetis, Laurent Piau, Leandro Martinez, Lenore M Mullin, Leonard Reuter, Leon Foks, Liam Portanier Mifsud, lm_lxt, Lori A. Burns, Luca, Luca Argenti, ludovicol, Luo Heng, Lysandro, Mark Johnson, Mark LeAir, Mark Wieczorek, Marshall Ward, Martin Diehl, Martín D. Maas, Martin Jambor, Mason, Matt Alex, Matthew Mitchell, Matthias Bussonnier, Matt Houston, Melissa Mendonça, Michael Hirsch, Michael Konecný, Michael Metcalf, Michael Rudko, Michael Siehl, Michael Zingale, Miguel Ras, Miguel Zuniga, mikola_jpp, Milad Sadeghi, Mitja, mobius-eng, Mohd Furqan, msz59, Nathaniel Shafer, Nathan Sircombe, nehrnd, Neels van Niekerk, Neil Carlson, Nick Papier, Nick Wigan, Nikola Vitas, Nocaster60, Oleg Peil, Oliver Furher, Oscar Garcia Cabrejo, Oscar Smith, oyvind, Pablo Santamaria, paul, Pedro Costa, Peter Brady, Peter Klausler, Peter Occil, Peter S. Simon, Philippe Blain, Philipp Engel, Pierre de Buyl, Pompeito, PrestonMag, qolin1, Rachitt Shah, Rashid Rafeek, rb, rcs, Reinh Bader, Reuben Budiardja, Richard Bleikamp, Richard Weed, Robert A Magliola, Robert Cohn, Robert D
Ryne, Robert Farmer, Roberto Putzu, Robert Ryley, Robert Van Amerongen, Rohit Goswami, Ron, Ron Caplan, Rong, Ron Shepard, Royi, Salvatore Filippone, Sam Harrison, Sam Partee, Samuel, Samuel (GF), Sascha Klawohn, Scot Halverson, Sebastian Janssens, Sebastian Costamagna, Sebastian Müller, Seif Shebl, septcolor, Shahid Maqbool, ShamanTcler, Sig Selene, Silvio Traversaro, Simon Braß, Simon Geard, Srinath Vadlamani, Stavros Meskos, Stefan Karpinski, Stephen Poole, Steve Kargl, Steve Lionel, Steve Westenbroek, St Maxwell, Tanweer Ali, Theodore-Thomas Tsikas, thierry, Thirumalai Shaktivel, Thomas Henlich, Tim, Tim Coupmodel, Tim Keith, Tim W, Tiziano Müller, Tom Clune, Tomohiro Degawa, Truong Dang, Tyler Chang, Uncle_Paul, Utkarsh Shah, v91_bleach, valterib, Van Snyder, victorsndvg, Vikas Sharma, Vincent Magnin, Vipul Parekh, Vladimír Fuka, Walt, Warrick Ball, waynelapierre, Wileam Y. Phan, Williams Lima, witenion_v2, Wolf Vollprecht, xushanthu, Yehan Wasura, Yuichiro Sakamoto, Yutaka Masuda, Zachary Moon, Zach Jibben, Zaikun, zmimz, Zuo Zhihua, and all other participants who engaged in fruitful discussions on Discourse, Twitter, and GitHub issues. We thank the Google Summer of Code program that sponsored six summer students (one through NumFOCUS) that worked on stdlib, fpm, and LFortran projects. We also thank J3 and WG-5 members who encouraged and supported our work on Fortran-lang. Ondřej Čertík’s work was partially supported by the U.S. Department of Energy through the Los Alamos National Laboratory. Los Alamos National Laboratory is operated by Triad National Security, LLC, for the National Nuclear Security Administration of U.S. Department of Energy (Contract No. 89233218CNA000001). All other Fortran-lang projects have been built by 100% volunteer effort.

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