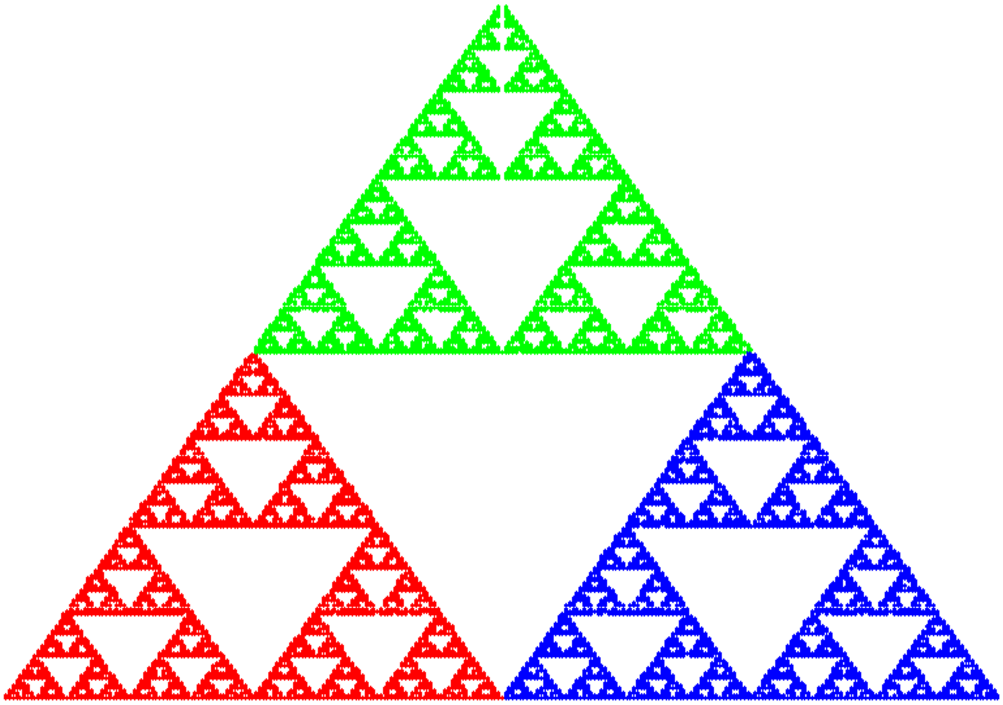
Introduction to Programming using Fortran 95



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Cover Diagram

The cover image is the plotted output from the *chaos game* program from chapter 11. The image was plotted with GNUplot.

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1 Introduction

Computers are everywhere in our daily lives. From the desktop, laptop, phone, bank, and vehicle, it is difficult to completely get away from computers. It only makes sense to learn a little about how a computer really works.

This text provides an introduction to programming and problem solving using the Fortran 95 programming language. This introduction is geared for non computer science majors. As such, this text is not a complete, comprehensive guide to the Fortran 95 programming language. The primary focus is on an introduction to problem solving and algorithm development. As such, many details of the Fortran 95 language are omitted.

1.1 Why Learn Programming

For science and technical majors, computers are used extensively in all aspects of a each discipline. Learning the basics of how computers work and how programs are created is useful and directly applicable.

Programming a computer is basically applied problem solving. You are given a problem, the problem is analyzed, a solution developed, then that solution is implemented and tested. Enhanced problem solving skills can be applied to any endeavor. These basic skills, once developed, can be applied to other programming languages, MATLAB, or even spreadsheet macro's.

Unfortunately, learning programing and how a computer really works may ruin some B movies.

1.2 Fortran

Fortran is a programming language often used by the scientific community. Its name is a contraction of FORmula TRANslation. FORTRAN is one of the earliest programming languages.

This text utilizes the Fortran 90/95 standard. Older versions of Fortran, like Fortran 77, are not referenced. The older Fortran versions have less features and require additional, often burdensome formatting requirements.

1.3 Complete Fortran 95 Documentation

This text it is not a comprehensive or complete reference to the Fortran 95 language. The entire GNU Fortran compiler documentation is available on-line at the following location:

```
http://gcc.gnu.org/onlinedocs/gcc-4.5.0/gfortran/
```

If this location changes, a web search will be able to find the new location.

1.4 What Is A Program

A *computer program* is a series of instructions which enables the computer to perform a designated task. As this text will demonstrate, a computer must be told what to do in precise, step-by-step detail. These steps might include obtaining data, arithmetic operations (additional, subtraction, multiplication, division, etc.), data storage, and information output. The computer will perform these tasks as instructed, even if they don't always make sense. Consequently, it is the programmer who must develop a solution to the problem.

1.5 Operating System

The Operating System, or OS, is an interface between the user and the hardware (CPU, memory, screen, disk drive, etc.). The OS is responsible for the management of the hardware, coordination of activities and the sharing of the resources of the computer that acts as a host for computing applications run on the machine. The common operating systems include various versions of Windows. MAC OS X, and UNIX/Linux. Programs written in Fortran will work on these operating systems.

2 Computer Organization

Before writing programs, it is useful to understand some basics about how a computer is organized. This section provides a brief, high-level overview of the basic components of a computer and how it is organized.

2.1 Architecture Overview

The basic components of a computer include a Central Processing Unit (CPU), Random Access Memory (RAM), Disk Drive, and Input/Output devices (i.e., screen and keyboard), and an interconnection referred to as BUS.

A very basic diagram of a computer architecture is as follows:

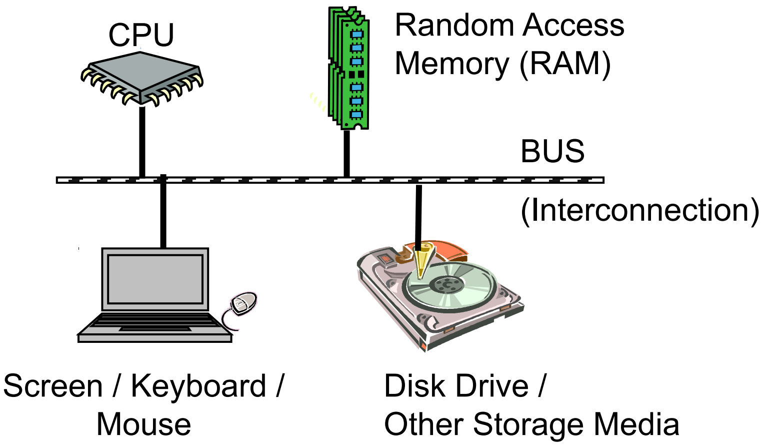


Illustration 1: Computer Architecture

Programs and data are typically stored on the disk drive. When a program is executed, it must be copied from the disk drive into the RAM memory. The CPU executes the program from RAM. This is similar to storing a term paper on the disk drive, and when writing/editing the term paper, it is copied from the disk drive into memory. When done, the updated version is stored back to the disk drive.

2.2 Compiler

Programs are written in the Fortran programming language. However, the CPU does not read Fortran directly. Instead, the Fortran program that we create will be converted into binary (1's and 0's) by the *compiler*. The CPU will read the instructions and information, represented in binary, and perform the commands from the program.

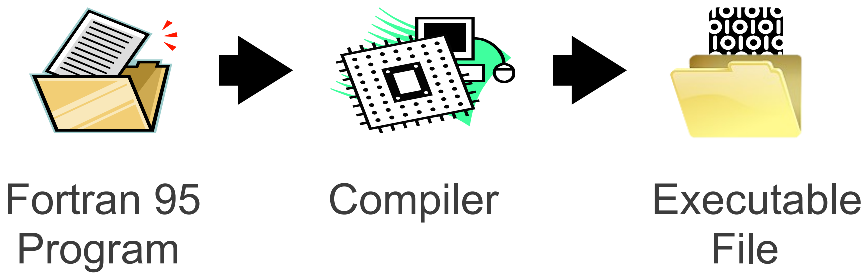


Illustration 2: Fortran 95 Compile Process

The compiler is a program itself and is required in order to create the files needed to execute programs written in Fortran 95.

2.3 Information Representation

All information, including numbers, characters, and instructions are represented in the computer in binary (1's and 0's). The information is converted into binary representation (1's and 0's) for storage in the computer. Fortunately, this is generally done transparently.

2.3.1 Decimal Numbers

Before discussing binary numbers, a brief review of the decimal system is presented. The number "1234" as,

Thousands	Hundreds	Tens	Ones
10^3	10^2	10^1	10^0
1000	100	10	1
1	2	3	4

Which means,

$$1234 = 1 \times 1000 + 2 \times 100 + 3 \times 10 + 4 \times 1$$
$$1234 = 1 \times 10^3 + 2 \times 10^2 + 3 \times 10^1 + 4 \times 10^0$$

The decimal system is *base 10* using the digits 0 through 9.

2.3.2 Binary Numbers

The binary system, as well as its math, operates in *base 2*, using two symbols, 0 and 1.

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
128	64	32	16	8	4	2	1
0	0	0	0	1	1	0	1

In base 2, we put the digits 0-1 in columns 2^0, 2^1, 2^3, and so on. For example,

$$1101_2 = 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 = 8+4+1$$

Which is decimal is 13_{10}.

2.3.3 Character Representation

Characters are represented using the American Standard Code for Information Interchange (ASCII). Refer to Appendix A.

2.4 Exercises

Below are some quiz questions based on this chapter.

2.4.1 Quiz Questions

Below are some quiz questions.

1) How is information represented in the computer?

2) What does the Fortran *compiler* do?

3) What architecture component connects the memory to the CPU?

4) What is 0000101_2 in decimal?

5) How are characters represented in the computer?

6) Where are programs stored when the computer is turned off?

7) Where must programs be located when they are executing?

3 Getting Started

This section provides a brief overview of how to get started. This includes the general process for creating a very simple program, compiling, and executing the program. Some detailed steps regarding working with files, obtaining the compiler, and compiling a program are included in *Appendix B, Windows Start-up Instructions*.

3.1 Required Skills

Before starting, you should have some basic computer skills, including the following:

- Ability to use a web browser
- Basic understanding of computer directory structure
- File manipulation (create, delete, rename, move, etc.)
- Ability to edit a text file
  - Includes selecting and learning a text editor (i.e., Notepad, Notepad++, emacs, etc.)

If you are unsure about any or all of these requirements you will need to learn them. Fortunately, they are not difficult. Additionally, there are numerous tutorials available on the Web.

The following sections assume the the Fortran 95 compiler is installed and available. For additional information regarding obtaining and installing the compiler, refer to Appendix B. The Fortran 95 compiler is available for download at no cost.

3.2 Program Formats

Fortran 95 programs must be written and formatted in a specific manner. The following sections summarize the basic program elements followed by a simple example.

3.2.1 Program Statement

A Fortran 95 program is started with a program statement, '**`program <name>`**', and ended with an end program statement, '**`end program <name>`**'. Refer to the example first program to see an example of these statements.

3.2.2 Comments

Comments are information for the programmer and are not read by the computer. For example, comments typically include information about the program. For programming assignments, the comments should include the programmer name, assignment number, and a brief description of the program.

3.2.3 Simple Output

A program can display a simple message to the screen by using the *write* statement. For example:

```
write(*,*) "Hello World"
```

Will display the message **Hello World** to the screen. Additional information regarding the write statement and outputting information is provided in later chapters.

3.2.4 Example – First Program

The following trivial program illustrates the initial formatting requirements.

```
! Simple Example Program
program first

      write (*,*) "Hello World"

end program first
```

In this example, the program is named 'first'. This file is typically referred to as the *source* file.

3.3 Text Editor

The first step is to create a text file named **hw.f95** using a text editor. It is useful to place programs and various files into a working directory. This way the files can be easily found and not confused with other, unrelated files and data. The **hw.f95** file should be created and placed in the working directory.

A file name is typically comprised of two parts; a name and an extension. In this example, the name is **hw** and the extension is **.f95**. The usual extension for this a future programs will be **.f95** which indicates that the file is a Fortran 95 source file.

The following examples will use the **hw.f95** file name. If desired, a different file name may be used. However, the name will need to be adjusted for the compiler and execute steps.

3.4 Compiling

Once the program is typed into a file, the file must be *compiled*. Compiling will convert the human readable Fortran program, or source file, into a computer readable version (in binary).

In the examples below, the commands typed by the user are displayed in bold. The regular (non-bolded) text refers to prompts or other information displayed by the computer (which will not need to be typed).

To compile the example program, the following command would be entered:

```
K:\mydir> gfortran -o hw hw.f95
```

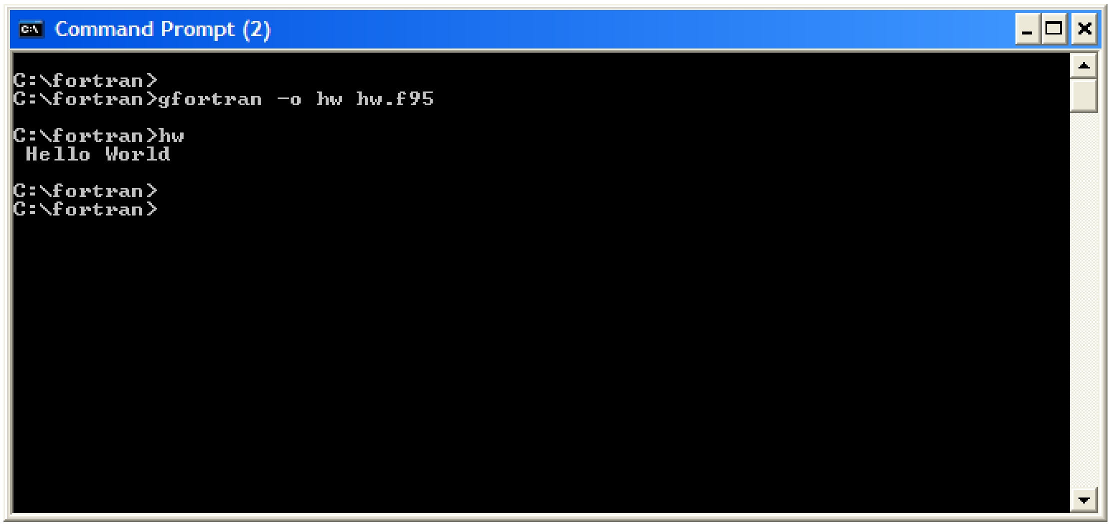
This command will tell the 'gfortran' compiler to read the file **hw.f95** and, if there are no errors, create an executable file named **`hw.exe`**. If there is an error, the compiler will generate an error message, sometimes cryptic, and provide a line number. Such errors are usually the result of mistyping one of the instructions. Any errors must be resolve before continuing.

3.5 Executing

To execute or run a program, type the name of the executable file. For example, to execute or run the ***hw.exe*** program:

```
K:\mydir> hw
 Hello World
K:\mydir>
```

Which will execute the example program and display the "Hello World" message to the screen. A more complete example is as follows:



```
C:\fortran>
C:\fortran>gfortran -o hw hw.f95

C:\fortran>hw
 Hello World

C:\fortran>
C:\fortran>
```

It is not necessary to type the extension (i.e., ".exe") portion of the file name.

3.6 Exercises

Below are some quiz questions and project suggestions based on this chapter.

3.6.1 *Quiz Questions*

Below are some quiz questions.

1) What the the input file for the compiler?

2) What is the output file from the compiler?

3) Fortran program must start with and end with what statement?

4) How are Fortran 95 comments marked?

5) What is the typical Fortran 95 source file extension?

6) What is the typical Fortran 95 compiler output file extension (after the program is compiled)?

3.6.2 Suggested Projects

Below are some suggested projects.

1) Create a working directory for the storage of program files (on the computer being used).

2) Obtain and install the GNU Fortran 95 compiler on a suitable computer. Refer to Appendix B as needed.

3) Type in the hello world program, compile, and execute the program.

4) Update the example program to display your name in addition to the Hello World message.

4 Fortran 95 – Basic Elements

Before beginning to writing programs, it is necessary to know some of the basic elements of the Fortran language. This section describes some of the basic elements of Fortran. Additional information will be added in later sections.

4.1 Variables

The basic concept in a program is the concept of a variable. Variables in a program are like variables in an algebraic expression. They are used to hold values and then write mathematical expressions using them. Fortran allows us to have variables of different types.

A variable can hold one value at a time. If another value is placed in the variable, the previous value is over-written and lost.

Variable Name → | 42 |

Variables must be declared at the start of the program before they are used.

4.1.1 Variable Names

Each variable must be named. The variable name is how variables, which are memory locations, are referred to by the program. A variable name must start with a letter, followed by letters, numbers, or an underscore ("_") and may not be longer than 32 characters. Capital letters are treated the same way as lower-case letters, (i.e., "AAA" is the same variable as "aaa").

For example, some valid variable names are as follows:

```
x
today
next_month
summation1
```

Some invalid examples include:

```
1today
this_is_a_variable_name_with_way_way_to_many_characters_in_it
next@month
next month
today!
```

Note that the space (between next and month) or the special character, @, is not allowed. Additionally, each variable must have a type associated as explained in the following sections.

4.1.2 Keywords

In programming, a keyword is a word or identifier that has a special Fortran meaning. For example, in the "hello world" program from the previous chapter, the word *program* had a special meaning in that it used to note the start or beginning of a program. Additionally, the word *write* has a special meaning to note an output action (e.g., writing some information to an output device, like the screen).

Such keywords are reserved in that they can not be used for anything else such variable names. That is, a variable name of program or write is not allowed.

As additional Fortran 95 statements and language constructs are explained, more keywords will identified. In general, words used for Fortran language statements, attributes, and constructs will likely be keywords. A complete list of keywords or reserved words is located in Appendix F.

4.2 Data Types

Fortran, like many other high level programming languages, supports several different *data types* to make data manipulation easier. The most frequently used data types are integer and floating point. Other data types are complex numbers, characters and logical data.

In a Fortran statement, data can appear either as a literal (e.g., an actual value such as 3.14159, 16, -5.4e-4) or as a variable name which identifies a location in memory to store the data.

The five basic Fortran 95 data types are as follows:

Type	**Description**
integer	Variable that is an integer or whole number (not a fraction) that can be positive, negative, or zero.
real	Variable that can set set to a real number.
complex	Variable that can be set to a complex number.
character	Variable that is a character or sequence of characters.
logical	Variable that can only be set to ***.true.*** or ***.false.***

It is also possible to have derived types and pointers. Both of these can be useful for more advanced programs and are described in later chapters.

4.2.1 Integer

An integer[1] is a whole number (not a fraction) that can be positive, negative, or zero. Examples include the numbers 10, 0, -25, and 5,148. Integers are the numbers people are most familiar with, and they serve a crucial role in mathematics and computers. All integers are whole numbers, so operations like one divided by two (1/2) is 0 since the result must be a whole number. For integer division, no rounding will occur as the fractional part is truncated.

[1] For more information regarding integers, refer to: http://en.wikipedia.org/wiki/Integer

4.2.2 Real

A real number[2] includes the fractional part, even if the fractional part is 0. Real numbers, also referred to as floating point numbers, include both rational numbers and irrational numbers. Examples of irrational numbers or repeating decimals include π, $\sqrt{2}$ and ***e***. Additional examples include 1.5, 5.0, and 3.14159. Fortran 95 will accept 5. as 5.0. All examples in this text will include the ".0" to ensure clarity.

4.2.3 Complex

A complex number[3], in mathematics, is a number comprising a real number and an imaginary number. It can be written in the form of $a + bi$, where a and b are real numbers, and the i is the standard imaginary unit with the property that $i^2 = -1.0$. The complex numbers contain the ordinary real numbers, but extend them by adding in extra numbers like an extra dimension. This data type is not used extensively, but can be useful when needed.

4.2.4 Character

A character[4] is a symbol like a letter, numerical digit, or punctuation. A string[5] is a sequence or set of characters. Characters and strings are typically enclosed in quotes. For example, the upper case letter "Z" is a character and "Hello World" is a string. The characters are represented in a standardized format referred to as ASCII.

4.2.5 Logical

A logical[6] is is only allowed to have two values, true or false. A logical is can also be referred to as a boolean. The true and false values are expressed as **.true.** or **.false.** which are called logical constants. The leading and trailing **.** (period) is required for the true and false constants.

4.2.6 Historical Data Typing

Unless a variable was explicitly typed, older versions of Fortran implicitly assumed a type for a variable depending on the first letter of its name. Thus, if not explicitly declared, a variable whose name started with one of the letters **I** through **O** was assumed to be an integer; otherwise it was assumed to be real. To allow older code to run, Fortran 95 permits *implicit typing*. However, this is poor practice and often leads to errors. So, we will include the IMPLICIT NONE statement at the start of all programs. This turns off implicit typing and the compiler will identify any variable not defined.

4.3 Declarations

Fortran variables must be declared before any executable statements. This section provides an introduction to how variables are declared.

[2] For more information regarding real numbers, refer to: http://en.wikipedia.org/wiki/Real_numbers

[3] For more information regarding complex numbers, refer to: http://en.wikipedia.org/wiki/Real_numbers

[4] For more information regarding characters, refer to: http://en.wikipedia.org/wiki/Character_(computing)

[5] For more infromation regarding strings, refer to: http://en.wikipedia.org/wiki/String_(computer_science)

[6] For more information regarding logicals, refer to: http://en.wikipedia.org/wiki/Boolean_data_type

4.3.1 Declaring Variables

Declaring variables formally defines the data type of each variable and sets aside a memory location. This is performed by a type declaration statement in the form of:

```
<type> :: <list of variable names>
```

The type must be one of the predefined data types (integer, real, complex, character, logical). Outlined in the previous section. Declarations are placed in the beginning of the program (after the program statement).

For example, to define an integer variable *today*,

```
integer :: today
```

Additional examples include:

```
integer :: today, tomorrow, yesterday
real :: ans2
complex :: z
logical :: answer
```

The declarations can be entered in any order.

Additional information regarding character variables is provided in a later chapter.

4.3.2 Initialization

It is possible to declare a variable and to set it is initial value at the same time. This initialization is not required, but can sometime be convenient. For example, to define an integer variable *todaysdate* and set it to the 15th of the month:

```
integer :: todaysdate=15
```

Additional examples include:

```
integer :: todaysday=15, tomorrow=16, yesterday=14
real :: ave = 5.5
```

Spaces or no spaces between the variables, equal signs, semicolons, and commas are allowed. Variables initialized at declaration can be changed later in the program as needed.

4.3.3 Constants

A *constant* is a variable that can not be changed during program execution. For example, a program might declare a variable for **π** and set it to 3.14159. It is unlikely that a program would need to change the value for the value for **π**. The parameter qualifier will set variable as a constant which sets the initial values and does not allow that initial value to be altered.

For example, the declarations:

```
real, parameter :: pi = 3.14159
integer, parameter :: width = 1280
```

will set the variable ***pi*** to 3.14159 and ***width*** to 1280 ensure that they can not be changed while thr program is executing.

4.4 Comments

Comments are information for the programmer and are not read by the CPU. For example, comments typically include information about the program. For programming assignments, the comments should include the programmer name, assignment number, and a description of the program.

4.5 Continuation Lines

A statement must start on a new line. If a statement is too long to fit on a line, it can be continued on the next line with an ampersand ('&'). Even shorter lines can be split and continued on multiple lines for more readable formatting. For example,

```
A = 174.5 * year               &
          + count / 100.0
```

Is equivalent to the following

```
A = 174.5 * year  + count / 100.0
```

Note that the '&' is ***not*** part of the statement.

4.5.1 Example

The following trivial program illustrates the program formatting requirements and variable declarations.

```
! Example Program

program example1

implicit none
integer :: radius, diameter
integer :: height=100, width=150
real :: area, perimeter
real :: length = 123.5, distance=413.761
real, parameter :: pi = 3.14159

      write (*,*) "Hello World"

end program example1
```

In this example, a series of variables are defined (as examples) but not used. The following chapters will address how to use the variables to perform calculations and display results.

4.6 Exercises

Below are some quiz questions and project suggestions based on this chapter.

4.6.1 Quiz Questions

Below are some quiz questions.

1) What are the five Fortran 95 data types?

2) What should a Fortran variable name start with?

3) What data type are each of the following numbers (integer or real)?

    475 ____________
    19.25 ____________
    19123 ____________
    5.0 ____________
    123.456 ____________

4) Write the statements required to declare ***value*** as an integer and ***count*** as a real.

5) Write the statements required to declare ***rate*** as an real initialized to 7.5.

6) Write the statements required to declare ***e*** as an real constant initialized to 2.71828183.

4.6.2 Suggested Projects

Below are some suggested projects.

1) Type in the *example1* example program, compile, and execute the program.

5 Expressions

This section describes how to form basic Fortran 95 expressions and perform arithmetic operations (i.e., add, subtract, multiple, divide, etc.). Expressions are formed using literals (actual values), variables, and operators (i.e., +, -, *, /, etc.). The previous chapter provides an explanation of what variable is and a summary of the five Fortran data types.

5.1 Literals

The simplest expression is a direct value, referred to as a *literal*. Since literals are actual values, not variables, they can not be changed. There are various types of literal constants described in the following sections, correspond to the data types.

5.1.1 Integer Literals

The following are some examples of *integer constants*:

```
1
0
-100
32767
+42
```

An integer must be a whole number (with no factional component).

5.1.2 Real Literals

The following are some examples of *real constants*:

```
1.0
-0.25
3.14159
```

The real number should include the decimal point (i.e., the "."). A real number includes the fractional part, even if the fraction is 0. Fortran will accept a number with the "." and no further digits. For example, 5. is the same as 5.0. All examples in this text will include the ".0" to ensure clarity.

5.1.2.1 E-Notation

For larger real numbers, *e-notation* may be useful. The e-notation means that you should multiply the constant by 10 raised to the power following the "E". This is sometimes referred to as scientific notation.

The following are some real constants using e-notation:

```
2.75E6
3.3333E-1
```

Hence, 2.75E5 is 2.75×10^{5} or 275,000 and 3.333E-1 is 3.333×10^{-1} or 0.3333 or approximately one third.

5.1.3 Complex Literals

A *complex constant* is designated by a pair of constants (integer or real), separated by a comma and enclosed in parentheses. Examples are:

```
(3.2, -4.1)
(1.0, 9.9E-1)
```

The first number denotes the real part and the second the imaginary part. While a complex number consits of two elements it is considered a single value.

5.1.4 Character Literals

A *character constant* is either a single character or a set of characters, called a string. A character is a single character enclosed in quotes. A string consists of an arbitrary sequence of characters also enclosed in quotes. Some examples include:

```
"X"
"Hello World"
"Good bye cruel world!"
"Have a nice day"
```

Character and string constants (enclosed with quotes) are case sensitive. So, character “X” (upper-case) is not the same as “x” (lower-case).

A problem arises if you want to have a quote in the string itself. A double quote will be interpreted as a single within a string.

```
"He said ""wow"" when he heard"
```

The double-quoting is sometimes referred to as an escape character. Strings and characters must be associated with the character data type.

5.1.5 Logical Constants

The fifth type is *logical constant*. These can only have one of two values:

```
.true.
.false.
```

The dots enclosing the true and false are required.

5.2 Arithmetic Operations

This section summarizes the basic arithmetic operations.

5.2.1 Assignment

Assignment is term for setting a variable equal to some value. Assignment is performed with a equal (=) sign. The general form is:

```
variable = expression
```

The expression may be a literal, variable, an arithmetic formula, or combination of each. Only one assignment to a single variable can be made per line.

For example, to declare the variable *answer1* as a real value,

```
real :: answer1
```

and set it equal to 2.71828183,

```
answer1 = 2.71828183
```

The value for *answer1* can be changed as often as needed. However, it can only hold one value at a time.

5.2.2 Addition

The Fortran addition operation is specified with a plus sign (+). For example, to declare the variables, *sum*, *number1*, *number2*, and *number3*,

```
integer :: sum, number1=4, number2=5, number3=3
```

and calculate the sum,

```
sum = number1 + number2
```

which will set the variable sum to 9 in this example. The data types of the variables, integer in this example, should be the same. Multiple variables can be added on one line. The line can also include literal values. For example,

```
sum = number1 + number2 + number3 + 2
```

which will set the variable *sum* variable to 14. Additionally, it will over-write the previous value of 9.

5.2.3 Subtraction

The Fortran subtraction operation is specified with a minus sign (-). For example, to declare the variables, *ans*, *value1*, *value2*, and *value3*,

```
real :: ans, value1=4.5, value2=2.5, value3=1.0
```

and calculate the difference,

```
ans = value1 – value2
```

which will set the variable ans variable to 2.0. The data types of the variables, real in this example, should be the same. Multiple variables can be subtracted on one line. The line can also include literal values. For example,

```
ans = value1 - value2 – value3
```

which will set the variable *ans* variable to 1.0. Additionally, it will over-write the previous value of 2.0.

5.2.4 Multiplication

The Fortran multiplication operation is specified with an asterisk (*). For example, to declare the variables, *ans*, *value1*, *value2*, and *value3*,

```
real :: ans, value1=4.5, value2=2.0, value3=1.5
```

and calculate the product,

```
ans = value1 * value2
```

which will set the variable *ans* to 9.0. The data types of the variables, real in this example, should be the same. Multiple variables can be multiplied on one line. The line can also include literal values. For example,

```
ans = value1 * value2 * 2.0 * value3
```

which will set the variable *sum* to 27.0. Additionally, it will over-write the previous value of 9.0.

5.2.5 Division

The Fortran division operation is specified with a slash symbol (/). For example, to declare the variables, *ans*, *value1*, *value2*, and *value3*,

```
real :: ans, value1=10.0, value2=2.5, value3=2.0
```

and calculate the quotient,

```
ans = value1 / value2
```

which will set the variable *ans* to 4.0. The data types of the variables, real in this example, should be the same. Multiple variables can be divided on one line. For example,

```
ans = value1 / value2 / value3
```

which will set the variable *sum* to 2.0. Additionally, it will over-write the previous value of 4.0.

5.2.6 Exponentiation

Exponentiation means "raise to the power of". For example, 2 to the power of 3, or 2^3 is (2 * 2 * 2) which is 8. The Fortran exponentiation operation is specified with a double asterisks (**).

For example, to declare the variables, *ans* and *value1*,

```
real :: ans, value1=2.0
```

and calculate the exponentiation,

```
ans = value1 ** 3
```

which will set the variable *ans* to 8.0. The data types of the variables, real in this example, should be the same.

5.3 Precedence of Operations

Fortran follows the standard mathematical precedence of operations. That is multiplication and division are performed before addition and subtraction. Further, in accordance with mathematical standards, the exponentiation operation is performed before multiplication and division.

The following table provides a partial summary of the basic Fortran 95 precedence levels:

Precedence Level	Operator	Operation
1st	-	unary -
2nd	**	exponentiation
3rd	* /	multiplication and division
4th	+ -	addition and subtraction

For operations of the same precedence level, the expression is evaluated left to right. Parentheses may be used to change the order of evaluation as necessary. For example, to declare the variables *ans1*, *ans2*, *num1*, *num2*, and *num3*.

```
integer :: ans1, ans2, num1=20, num2=50, num3=10
```

and calculate the *ans1* and *ans2*,

```
ans1 = num1 + num2 * num3
ans2 = (num1 + num2) * num3
```

which will set to *ans1* to 520 and *ans2* to 700 (both integers).

5.4 Intrinsic Functions

Intrinsic functions are standard built-in functions that are provided by Fortran. These include a rich set of standard functions, including the typical mathematical standard functions. Intrinsic functions can be used in expressions as needed. Most intrinsic functions accept one or more arguments as input and return a single value.

5.4.1 Mathematical Intrinsic Functions

The built-in functions include the standard mathematical functions such as sine, cosine, tangent, and square root.

For example, the cosine of ***π*** is -1. In Fortran, to declare the variables ***x*** and ***pi***,

```
real :: z
real, parameter :: pi = 3.14159
```

and then calculate the cosine of the variable *pi*,

```
z = cos(pi)
```

which will set *z* to -1.0. The variable ***pi*** is the input argument and the result returned is assigned to the variable *z*.

5.4.2 Conversion Functions

Other intrinsic functions include functions to change the type of variables or values. The basic conversion functions are as follows:

Function	Explanation
real(<integer argument>)	Convert the <integer argument> to a real value
int(<real argument>)	Convert the <real argument> to an integer, truncates the fractional portion
nint(<real argument>)	Convert the <real argument> to an integer, rounds the fractional portion

For example, given the following variable declarations,

```
integer :: inum1=10, inum2, inum3
real :: rnum1, rnum2 = 4.8
```

and calculate the *ans1* and *ans2*,

```
rnum1 = real(inum1)
inum2 = int(rnum2)
inum3 = int(rnum3)
```

which will set to *rnum1* to 10.0, *inum2* to 4, and *inum3* to 5.

5.4.3 Summary

A summary of some of the more common intrinsic functions include:

Function	Description
COS(W)	Returns real cosine of real argument W in radians.
INT(A)	Converts real argument A to integer, truncating (real part) towards zero.
MOD(R1,R2)	Returns remainder after division of R1 on division by R2. Result, R1 and R2 should be all integer or all real types.

NINT(X)	Returns the nearest integer to real value X (thus rounding up or down as appropriate).
REAL(A)	Converts integer argument A to real.
SIN(W)	Returns real sine of real argument W in radians.
SQRT(W)	Returns the real square root of real argument W; W must be positive.
TAN(X)	Returns the real tangent of real argument X in radians.

A more complete list of intrinsic functions in located in Appendix B.

5.5 Mixed Mode

In general, mathematical operations should be performed on variables of the same type. When both integer and real values or variables are used in the same statement, it is called mixed mode.

Real and integer operations:

```
1/2 = 0
1.0 + 1/4 = 1.0
1.0 + 1.0/4 = 1.25
```

when mix-mode is encountered, integer is converted to real only when mixed-mode is encountered on the same operation type. Conversion may also occur on assignment.

Unexpected conversions can cause problems when calculating values. In order to avoid such problems, it is strongly recommended to not use mix-mode. There are a series of rules associated with mixed-mode operations. For simplicity, those rules are not covered in here.

If it is necessary to perform calculations with different data types, like integers and reals, the conversion functions should be used correct and predictable results.

5.6 Examples

Below is an example program that calculates velocity based on acceleration and time. The program declares the appropriate variables and calculate the velocity.

```
program velocity
! Program to calculate the velocity from the
! acceleration and time

! Declare variables
implicit none
real :: velocity, acceleration = 128.0
real :: time = 8.0

! Display initial header
      write (*,*) "Velocity Calculation Program"
      write (*,*)
      ! Calculate the velocity
           velocity = acceleration * time

           write (*,*) "Velocity = ", velocity

      end program velocity
```

Additional information regarding how to perform input and output in the next chapter. The comments are not required, but help make the program easier to read and understand.

5.7 Exercises

Below are some quiz questions and project suggestion based on this chapter.

5.7.1 Quiz Questions

Below are some quiz questions.

1) What is *assignment* operator?

2) What is the exponentiation operator?

3) How can an integer variable be converted to a real value?

4) How can an real variable be converted to a integer value?

5) What are the two logical constants?

6) List three intrinsic functions.

7) Write the single Fortran statement for each of the following formulas:

$$x1 = \left(\frac{\pi}{6}\right)\left(3a^2+3b^2+c^2\right)\, c$$

$$x2 = -\frac{2a}{c}\,\cos(b)\,\sin(b)$$

$$x3 = \frac{-b \pm \sqrt{(b^2-4ac)}}{2a}$$

5.7.2 Suggested Projects

Below are some suggested projects.

1) Type in the velocity program, compile, and execute the program. Change the declared values, compile, and execute the modified program. Verify the results of both executions with a calculator.

2) Write a program to calculate and display the difference between time as read from a sundial and a clock. The difference can be calculated with the "equation of time" which is:

$$\begin{aligned} b &= 2\,\pi\,(n - 81)\,/\,364 \\ e &= 9.87\ \sin(2\mathrm{b}) - 7.53\ \cos(b) - 1.5\ \sin(b) \end{aligned}$$

Where, ***n*** is the day number. For example, ***n*** = 1 for January 1, ***n*** = 2 for January 2, and so on. The program should read the value for ***n*** (1-364) from the user and an integer. The program should perform the appropriate type conversions, perform the required calculations, and display the ***n***, ***b***, and final ***e*** values. Test the program on a series of different values.

6 Simple Input and Output

Simple, unstructured, input and output can be performed with the *write* and *read* statements as explained in the following sections. In a later chapter, a more structured approach will be presented in later sections.

6.1 Output – Write

As noted from the first program, simple output can be performed by using the a *write* statement. For example:

```
write (*,*) "Hello World"
```

Which will send the message, referred to as a *string*, **Hello World** to the screen. The first "*" means the default output device, which is the screen or monitor. The second "*" refers to the 'free format'. Thus, the "`(*,*)`" means to send it to the screen in 'free format'.

The free format allows the Fortran compiler to determine the appropriate format for the information being displayed. This is easy, especially when first getting started, but does not allow the program much control over how the output will be formatted or displayed on the screen.

Additionally, the value held by declared variables can be displayed. For example, to declare the variables *num1*, *num2*, and *num3*.

```
integer :: num1=20, num2=50, num3=10
```

the write statement to display *num1* would be,

```
write (*,*) num1
```

The free format allows the Fortran compiler to determine the appropriate output format for the information being displayed.

A write statement with no string or variables,

```
write (*,*) num1
```

Will display a blank line.

Multiple variables and strings can be displayed with one write statement. For example, using the previous declarations,

```
write (*,*) "Number 1 = ", num1, "Number 2 = ", num2
```

The information inside the quotes is displayed as is, including capitalization and any spelling errors. When the quotes are not used, it is interpreted as a variable. If the variable is not declared, a compiler error will be generated. The value assigned to each variable will be displayed. A value must have be assigned to the variable prior to attempting to display.

6.1.1 Output – Print

In addition to the write statement, a print statement can be used. The print statement will send output only to the screen. Thus it is a more restrictive form of the write statement.

As with the write statement, multiple variables and strings can be displayed with one print statement. For example, using the previous declarations,

```
print *,"Number 1 = ", num1, "Number 2 = ", num2
```

The information inside the quotes is displayed as is, including capitalization and any spelling errors. When the quotes are not used, it is interpreted as a variable. If the variable is not declared, an error will be generated. If the variable is defined, the value assigned to that variable will be displayed.

In general, all examples will use the write statement.

6.2 Input – Read

To obtain information from the user, a *read* statement is used. For example, to declare the variables *num1*, *num2*,

```
integer :: ans1, ans2
```

then read a value for *ans1* from the user,

```
read (*,*) ans1
```

Which will read a number from the user entered on the keyboard into the variable *ans1*. The (*,*) means to send it to read the information in 'free format'. The free format allows the Fortran compiler to determine the appropriate format for the information being read.

Multiple variables can be read with one write statement. For example, using the previous declarations,

```
read (*,*) ans1, ans2
```

will read two values from the user into the variables *ans1* and *ans2*.

Since the read is using free format, two numbers will be required. The numbers can be entered on the same line with one more more spaces between them or on separate lines. The read will wait until two numbers are entered.

When reading information from the user, it is usually necessary to provide a prompt in order to ensure that the user understands that input is being requested by the program. A suitable write statement with an appropriate string, followed by a read statement will ensure that the user is notified that input is being requested.

For example, to read a date, a program might request month, date, and year as three separate variables. Given the following declarations,

```
integer :: month, date, year
```

the program might prompt for and read the data in the following manner,

```
write (*,*) "Enter date (month, date, and year)"
read (*,*) month, date, year
```

Since the program is requesting three integers, three integers must be entered before the program continues. The three numbers may be entered on one line with a single space between them, with multiple spaces or tab between them, or even on three different lines as in the following examples:

```
Enter date (month, date, and year)
10 17 2009

Enter date (month, date, and year)
10
17
2009

Enter date (month, date, and year)
10          17    2009
```

The type of number requested here is an integer, so integers should be entered. Providing a real number or character (i.e., letter) would generate an error. Later chapters will address how to deal with such errors.

6.3 Example

Below is an example program that calculates the area of a circle. The program will declare the appropriate variables, read the radius, calculate the circle area, and display the result.

```
Program circle
! Program to calculate the area of a circle

! Declare variables
implicit none
real :: radius, area
real, parameter :: pi = 3.14159

! Display initial header and blank line
      write (*,*) "Circle Area Calculation Program"
      write (*,*)

! Prompt for and read the radius
      write (*,*) "Enter Circle Radius"
      read (*,*) radius

! Calculate the circle area
      area = pi * radius**2

! Display result
      write (*,*) "Circle Area:   ", area

end program circle
```

The comments are not required, but help make the program easier to read and understand. If the program does not work at first, the comments can aid in determining the problem.

6.4 Exercises

Below are some quiz questions and project suggestions based on this chapter.

6.4.1 Quiz Questions

Below are some quiz questions.

1) What does the **(*,*)** mean?

2) What is the statement to output a message "Programming is Fun!"

3) What are the statements to declare and read the value for a persons age in years.

6.4.2 Suggested Projects

Below are some suggested projects.

1) Type in the circle area program, compile and execute the program. Test the program on several sets of input.

2) Modify the circle area program to request a circle diameter. The formula for circler area must be adjusted accordingly. Recall that radius = diameter divided by two. Test the program on several sets of input.

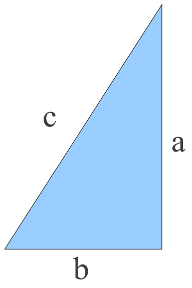
3) Type in the velocity program from the previous chapter and update to prompt for and request input for the acceleration and time, and then display the results. Test the program on several sets of input.

4) Write a Fortran program to read the length of the ***a*** and ***b*** sides of a right triangle and compute the perimeter length. The program should prompt for input and display the values for sides ***a***, ***b***, ***c***, and the perimeter with appropriate headings.

   Recall that:

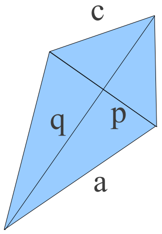
$$c = \sqrt{a^2 + b^2}$$

$$perimeter = a + b + c$$



   Test the program on several sets of input.

5) Write a Fortran program compute geometric information for a Kite. The program should read the ***a***, ***c*** and ***p*** lengths and compute the ***q*** length. The program should display an appropriate prompt, read the values, compute the answer, and display the original input and the final result.



Recall that:

$$q = \sqrt{\left(a^2 - \frac{p^2}{4}\right)} - \sqrt{\left(c^2 - \frac{p^2}{4}\right)}$$

Test the program on several sets of input.

7 Program Development

Writing or developing programs is easier when following a clear methodology. The main steps in the methodology are:

- Understand the Problem
- Create the Algorithm
- Develop the Program
- Test/Debug the Program

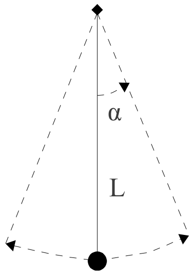
To help demonstrate this process in detail, these steps will be applied to a simple problem to calculate and display the period of a pendulum.

As additional examples are presented in later chapters, they will be explained and presented using this methodology.

7.1 Understand the Problem

Before attempting to create a solution, it is important to understand the problem. Ensuring a complete understanding of the problem can help reduce errors. The first step is to understand the what is required and the applicable input information. In this example, the formula for the period of a pendulum is:

$$Period = 2\pi \sqrt{\frac{L}{g}} \left(1 + \frac{1}{4} \sin^2 \left(\frac{\alpha}{2} \right) \right)$$



Where:

g = 980 cm/sec^2
π = 3.14159
L = Pendulum length (cm)
α = Angle of displacement (degree)

Both g (gravity) and π should be declared as a constants. The formula is a simplified version of the more general case. As such, for very large, very small, or zero angle values the formula will not provide accurate results. For this example, that is acceptable.

As shown, the pendulum is attached to a fixed point, and set into motion by displacing the pendulum by an angle, α, as shown in the diagram. The program must define the constants for g and π, declare the variables, display appropriate prompts, read the values for L and α, then calculate and display the original input and the period of the pendulum with the given length and angle of displacement.

7.2 Create the Algorithm

The algorithm is the name for the ordered sequence of steps involved in solving the problem. Once the program is understood, a series of steps can be developed to solve that problem. There can be multiple correct solutions to a given problem.

The process for creating an algorithm can be different for different people. In general, some time should be devoted to thinking about a possible solution. This may involve working on some possible solution on a scratch piece of paper. Once a possible solution is selected, that solution can be developed into an algorithm. The algorithm can be written down, reviewed, and refined. This algorithm is the outline of the program.

For this problem, the variables and constants must be declared, the applicable headers and prompts displayed, and the values for ***L*** and ***α*** read from the user. Then the period can be calculated based on the provided formula and the results displayed. Formalizing this, the following steps can be developed and written down as follows:

```
! declare variables
!     real constants -> gravity, pi
!     reals -> angle, length
! display initial header
! prompt for and read the length and angle values
! calculate the period
! display the results
```

While this is a fairly straightforward algorithm, more complex problems would require more extensive algorithms. Examples in later chapters will include more complex programs. For convenience, the steps are written a program comments. This will allow the addition of the code to the basic algorithm.

7.3 Develop the Program

Based on the algorithm, the following program can be created.

```
program period
! Program to calculate the period of a pendulum

! declare variables
!     real constants -> gravity, pi
!     reals -> angle, length
implicit none
real :: angle, length, pperiod
real, parameter :: gravity=980.0, pi=3.14159

! display initial header
      write (*,*) "Pendulum Period Calculation Program"
      write (*,*)

! prompt for and read the length and angle values
      write (*,*) "Enter Length and Angle values:"
      read (*,*) length, angle
```

```
! calculate the period
      pperiod = 2.0 * pi * sqrt(length/gravity) *         &
                        ( 1.0 + 1.0/4.0 * sin(angle/2.0)**2 )

! display the results
      write(*,*) "The period is:", pperiod

end program period
```

The indentation is not required, but helps make the program easier to read. Note that the “2”, “1”, and “4” in the algorithm are entered as 2.0, 1.0, and 4.0 to ensure consistent data typing (i.e., all reals). If the 1 over 4 is entered as “1/4” instead of “1.0/4.0”, it be incorrect since “1/4” would provide a result of 0 (since this would be integer division).

7.4 Test/Debug the Program

Once the program is written, testing should be performed to ensure that the program works. The testing will be based on the specific parameters of the program. In this example, each of the three possible values for the discriminant should be tested.

```
C:\mydir> period

Pendulum Period Calculation Program

Enter Length and Angle values:
120.0  15.0

 The Period is:    2.682276

K:\mydir>
```

As before, input typed by the user is shown in bold. For this program, the results can be verified with a calculator. A series of different values should be used for testing. If the program does not work, the program comments provide a checklist of steps and can be used to help debug the program.

7.4.1 Error Terminology

In case the program does not work, it helps to understand some basic terminology about where or what the error might be.

7.4.1.1 Compiler Error

Compiler errors are generated when the program is compiled. This means that the compiler does not understand the instructions. The compiler will provide a list of errors and the line number the of each error. It is recommended to address the errors from the top down. Resolving an error at the top can clear multiple errors further down.

Typical compiler errors include misspelling a statement and/or omitting a variable declaration. For example, if the correct Fortran statement “write (*,*)” is entered incorrectly as “wrote (*,*)”, an error will be generated.

In this case, the compiler error displayed will appear as follows:

```
c:\mydir> gfortran -o period period.f95
period.f95:13.1:

 wrote (*,*)
1
Error: Unclassifiable statement at (1)
```

The first digit, 13 in this example, represents the line number where the error occurred. Using a text editor that displays line numbers, the statement that caused the error can be quickly found and corrected.

If the declaration for the variable *length* is omitted, the error would appear as follows:

```
c:\mydir> gfortran -o period period.f95
period.f95:17.18:

 read (*,*) length, angle
                 1
Error: Symbol 'length' at (1) has no IMPLICIT type
```

In this case, the error is shown on line 18 (first digit after the “:”). However, the actual error is that the variable length is not declared. Each error should be reviewed and evaluated.

7.4.1.2 Run-time Error

A run-time error is something that causes the program to crash. For example, if the a number is requested from the user and a letter is entered, that can cause occur.

For example, the period program expects two real numbers to be entered. If the user enters letters, x and y, in this example, an error will be generated during the execution of the program as follows:

```
c:\mydir> period
Pendulum Period Calculation Program

Enter Length and Angle values:
x y
At line 17 of file period.f95 (unit = 5, file = 'stdin')
Fortran runtime error: Bad real number in item 1 of list input
```

The program was expecting numeric values and letters were provided. Since letters are not meaningful in this context, it is an error and the program “crashes” or stops with an error message.

Later chapters will provide additional information on how to deal with such errors. Until then, proving the correct data type will avoid this kind of error.

7.4.1.3 Logic Error

A logic error is when the program executes, but does not produce the correct result. For example, coding a provided formula incorrectly or attempting to computer the average of a series of numbers before calculating the sum.

For example, the correct formula for the period of a pendulum is as follows:

```
pperiod = 2.0 * pi * sqrt(length/gravity) *          &
                        ( 1.0 + 1.0/4.0 * sin(angle/2.0)**2 )
```

If the formula is typed incorrectly or incompletely as follows:

```
pperiod = 2.0 * pi * sqrt(length/gravity) *          &
                        ( 1.0 + 1/4 * sin(angle/2.0)**2 )
```

The 1 over 4 is entered as "1/4" which are interpreted as integers. As integers, "1/4" results in 0. The compiler will accept this, perform the calculations, and provide an incorrect result.

The program would compile and execute as follows.

```
c:\mydir> period
 Pendulum Period Calculation Program

 Enter Length and Angle values:
120.0 15.0
 The period is:   2.198655
```

However, an incorrect answer would be generated as shown. This is why testing the program is required. Logic errors can be the most difficult to find.

One of the best ways to handle logic errors is to avoid them by careful developing the algorithm and writing the code.

If the program has a logic error, one way to find the error is to display intermediate values. Further information will be provided in later chapters regarding advice on finding logic errors.

7.5 Exercises

Below are some quiz questions and project suggestions based on this chapter.

7.5.1 Quiz Questions

Below are some quiz questions.

1) What are the four program development steps?

2) What are the three types of errors?

3) If a program to compute the area of a rectangle uses a formula, ***height*** × ***height*** × ***width***, what type of error would this be?

4) Provide an example of that would generate a compiler error.

7.5.2 Suggested Projects

Below are some suggested projects.

1) Type in the pendulum period calculation program, compile, and execute the program. Test the program using several different input values.

2) Create a program to prompt for and read the circle area from the user and calculate the circumference of a circle using the following formula:

$$circumference = 2\sqrt{\pi\ CircleArea}$$

Test the program using several different input values.

3) Create a program to prompt for and read the radius of a sphere from the user and calculate the surface area of the sphere using the following formula:

$$sphere\,Surface\ Area = 4\pi r^2$$

Test the program using several different input values.

4) Create a program to prompt for and read the radius of a sphere from the user and calculate the sphere volume using the following formula:

$$sphere\,Volume = (4\pi/3)r^3$$

Test the program using several different input values.

8 Selection Statements

When writing a program, it may be necessary to take some action based on the outcome of comparing the values of some variables. All programming languages have some facility for decision-making. That is, doing one thing if some condition is true and (optionally) doing something else if it is not.

Fortran IF statements and/or CASE statements are used to allow a program makes decisions.

8.1 Relational Expressions

The first step is to compare two values, often contained in variables. The way two values are compared is with relational operators. The variables are often referred to as *operands*. Relational operators are used between variables or operands of similar types. That is real to real, integer to integer, logical to logical, and character/string to character/string.

The basic relational operators are:

Relational Operation	**Relational Operator (normal)**	**Relational Operator (alternate)**
Greater than	>	**.gt.**
Greater than or equal	>=	**.ge.**
Less than	<	**.lt.**
Less than or equal	<=	**.le.**
Equal to	==	**.eq.**
Not equal to	/=	**.ne.**

The normal form will be used for examples in this text. However, the alternate form may be used at any time. The alternate forms are used to support older Fortran programs.

A relational operation is used to form a relational expression. The result of a relational expression must always result in either a *true* or *false* result.

The "==" (two equal signs) is used to compare. The "=" (single equal) is used for assignment (setting a variable). The "==" does not change any values, while the "=" does.

For example, given the declaration of,

```
integer :: gamelives
```

it might be useful to know if the current value of **`gamelives`** is greater than 0.

In this case, the relational expression would be,

```
            (gamelives == 0)
```

Which will result in a *true* or *false* result based on the value of “gamelives”.

8.2 Logical Operators

Logical operators are used between two logical variables or two logical expressions. They are:

Logical Operator	Explanation
.and.	the result is true if ***both*** operands are true
.or.	the result is true if ***either*** operand is true
.not.	logical negate (if true, makes false and if false, makes true)

Logical operators are used to combine relational operations as needed.

For example, given the declaration of,

```
            integer :: gamelives, extralives
```

it might be useful to know if the current value of `gamelives` is greater than 0. In this case, the relational operation would be,

```
            ( (gamelives == 0) .and. (extralives == 0) )
```

which will result in a *true* or *false* result. Since the AND logical operation is used, the final result will be *true* only if both logical expressions are *true*.

Another way of check the status might be,

```
            ( (gamelives > 0) .or. (extralives > 0) )
```

which still results in a *true* or *false* result. However, since the **or** logical operation is used, the final result will be *true* if either logical expressions is *true*.

The relational operators have higher precedence than logical operators.

8.3 IF Statements

IF statements are used to perform different computations or actions based on the result of a logical expression (which evaluates to true or false). There are a series of different forms of the basic IF statement. Each of the forms is explained in the following sections.

8.3.1 IF THEN Statement

The IF statement, using the relational operators, is how programs make decisions. The general format for an IF statement is as follows:

```
if ( <relational expression> ) then
      <fortran statement(s)>
end if
```

Where the <fortran statements> may include one or more valid Fortran statements.

For example, given the declaration of,

```
integer :: gamelives
```

based on the current value of **`gamelives`** is, a reasonable IF statement might be:

```
if ( gamelives == 0 ) then
      write (*,*) "Game Over."
      write (*,*) "Please try again."
end if
```

Which will display the message “Game Over” if the value of **`gamelives`** is less than or equal to 0.

8.3.1.1 IF THEN Statement, Simple Form

Additionally, another form of the IF statement includes

```
if ( <relational expression> ) <fortran statement>
```

In this form, a single statement is executed if the relational expression evaluates to true. The previous example might be written as

```
if ( gamelives == 0 ) write (*,*) "Game Over."
```

In this form, no “then” or “end if” are required. However, only one statement can be executed.

8.3.2 IF THEN ELSE Statement

The IF THEN ELSE statement expands the basic IF statement to also allow a series of statements to be performed if the logical expression evaluates to *false*.

The general format for an IF THEN ELSE statement is as follows:

```
if ( <relational expression> ) then
      <fortran statement(s)>
else
      <fortran statement(s)>
end if
```

Where the <fortran statements> may include one or more valid Fortran statements.

For example, given the declaration of,

```
integer :: gamelives
```

based on the current value of **gamelives** is, a reasonable IF THEN ELSE statement might be:

```
if ( gamelives > 0 ) then
      write (*,*) "Still Alive, Keep Going!"
else
      write (*,*) "Extra Life Granted."
      gameslives = 1
end if
```

Which will display the message "Still Alive, Keep Going" if the value of **gamelives** is greater than 0 and display the message "Extra Life Granted" if the value of **gamelives** is less than 0.

8.3.3 IF THEN ELSE IF Statement

The IF THEN ELSE IF statement expands the basic IF statement to also allow a series of IF statements to be performed in a series.

The general format for an IF THEN ELSE IF statement is as follows:

```
if ( <relational expression> ) then
      <fortran statement(s)>
else if ( <relational expression> ) then
      <fortran statement(s)>
else
      <fortran statement(s)>
end if
```

Where the <fortran statements> may include one or more valid Fortran statements.

For example, given the declaration of,

```
integer :: gamelives
```

based on the current value of **gamelives** is, a reasonable IF THEN ELSE IF statement might be:

```
if ( gamelives > 0 ) then
      write (*,*) "Still Alive, Keep Going!"
else if ( gamelives < 0 )
      write (*,*) "Sorry, game over."
else
      write (*,*) "Extra Life Granted."
      gameslives = 1
end if
```

Which will display the message "Still Alive, Keep Going" if the value of **gamelives** is greater than 0, display the message "Sorry, game over" if the value of game lives is < 0, and display the message "Extra Life Granted" if the value of **gamelives** is equal to 0.

8.4 Example One

As previously described, writing or developing programs is easier when following a methodology. As the program become more complex, using a clear methodology is even more important. The main steps in the methodology are:

- Understand the Problem
- Create the Algorithm
- Develop the Program
- Test/Debug the Program

To help demonstrate this process in detail, these steps will be applied to a familiar problem as an example. The example problem is to calculate the solution of a quadratic equation in the form:

$$a x^2 + b x + c = 0$$

Each of the steps, as applied to this problem will be reviewed.

8.4.1 Understand the Problem

Before creating a solution, it is important to understand the problem. Ensuring a complete understanding of the problem can help reduce errors.

It is known that the solution to the quadratic equation is as follows:

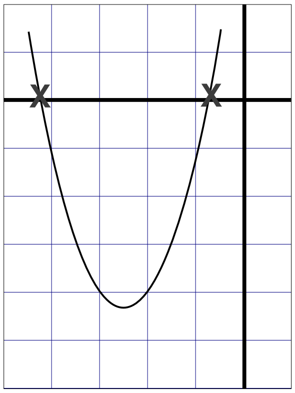
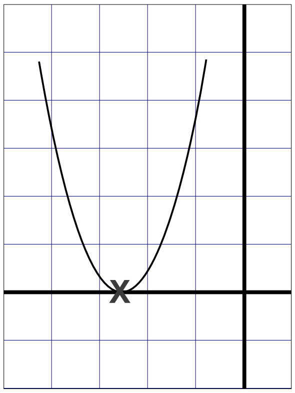
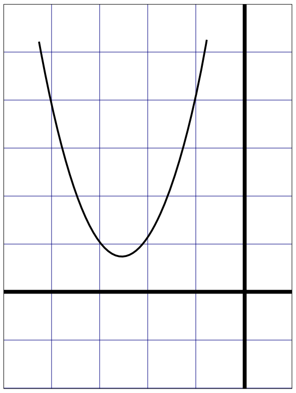
$$x = \frac{-b \pm \sqrt{(b^2 - 4 a c)}}{2 a}$$

In the quadratic equation, the term $(b^2 - 4 a c)$ is the *discriminant* of the equation. There are three possible results for the discriminant as described below:

- If $(b^2 - 4 a c) > 0$ then there are two distinct real roots to the quadratic equation. These two solutions represent the two possible answers. If the equation solution is graphed, the curve representing the solution will cross the $\boldsymbol{x}$-axis (i.e., representing $\boldsymbol{x}$=0) in two locations.
- If $(b^2 - 4 a c) = 0$ then there is a single, repeated root to the equation. If the equation solution is graphed, the curve representing the solution will cross the $\boldsymbol{x}$-axis in one location.
- If $(b^2 - 4 a c) < 0$ then there are two complex roots to the equation. If the equation solution is graphed, the curve representing the solution will not cross the $\boldsymbol{x}$-axis and this no real number solution. However, mathematically the square root of a negative value will provide a complex result. A complex number includes a real component and an imaginary component.

A correct solution must address each of these possibilities. For this problem, it is appropriate to use real values.

The relationship between the discriminant and the types of solutions (two different solutions, one repeated solution, or no real solutions) is summarized in the below table:

Positive Discriminant	**Zero Discriminant**	**Negative Discriminant**
Two real solutions	One real solution	Two complex solutions
Example: $3x^2-9x-3$	Example: $2x^2-4x-2$	Example: $3x^2-3x-3$
		
Two distinct ***x***-intercepts	One ***x***-intercept	No ***x***-intercept

Root 1 = -0.382
Root 2 = -2.618
	Root 1 = -1.0	Root = -0.5 + 0.866
		Root = -0.5 - 0.866

The examples provided above are included in the example solution in the following sections.

8.4.2 Create the Algorithm

The algorithm is the name for the ordered sequence of steps involved in solving the problem. The variables must be defined and an initial header displayed. For this problem, the ***a***, ***b***, and ***c*** values will need to be read from the user. Formalizing this, the following steps can be developed.

```
! declare variables
!     reals -> a, b, c, discriminant, root1, root2
! display initial header
! read the a, b, and c values
```

Then, the discriminant can be calculated.

Based on the discriminant value, the appropriate set of calculations can be performed.

```
! calculate the discriminant
! if discriminant is 0,
!     calculate root
! if discriminant is >0,
!     calculate root1 and root2
!     display root1 and root2
! if discriminant is >0,
!     calculate complex root1 and root2
!     display complex root1 and root2
```

For convenience, the steps are written a program comments.

8.4.3 Develop the Program

Based on the algorithm, the following program can be created.

```
program quadratic
! Quadratic equation solver program

! declare variables
!     reals -> a, b, c, discriminant, root1, root2
implicit none
real :: a, b, c
real :: discriminant, root1, root2

! display initial header
write (*,*) "Quadratic Equation Solver Program"
write (*,*) "Enter A, B, and C values"

! read the a, b, and c values
read (*,*) a, b, c

! calculate the discriminant
discriminant = b ** 2 – 4.0 * a * c

! if discriminant is 0,
!     calculate root
if ( discriminant == 0 ) then
      root1 = -b / (2.0 * a)
      write(*,*) "This equation has one root:"
      write(*,*) "root = ", root1
end if

! if discriminant is >0,
!     calculate root1 and root2
!     display root1 and root2
if ( discriminant > 0 ) then
      root1 = (-b + sqrt(discriminant)) / (2.0 * a)
      root2 = (-b - sqrt(discriminant)) / (2.0 * a)
      write(*,*) "This equation has two real roots:"
      write(*,*) "root 1 = ", root1
      write(*,*) "root 2 = ", root2
end if

! if discriminant is >0,
!     calculate complex root1 and root2
!     display complex root1 and root2
if ( discriminant < 0 ) then
      root1 = -b / (2.0 * a)
      root2 = sqrt(abs(discriminant)) / (2.0 * a)
      write(*,*) "This equation has two real roots:"
      write(*,*) "root 1 = ", root1, "+i", root2
      write(*,*) "root 2 = ", root1, "-i", root2
end if

end program quadratic
```

The indentation is not required, but does help make the program easier to read.

8.4.4 Test/Debug the Program

Once the program is written, testing should be performed to ensure that the program works. The testing will be based on the specific parameters of the program. In this example, each of the three possible values for the discriminant should be tested.

```
C:\mydir> quad
 Quadratic Equation Solver Program
 Enter A, B, and C values
2 4 2
 This equation has one root:
 root =   -1.0000000

C:\mydir> quad
 Quadratic Equation Solver Program

 Enter A, B, and C values
3 9 3
 This equation has two real roots:
 root 1 =  -0.38196602
 root 2 =   -2.6180339

C:\mydir> quad
 Quadratic Equation Solver Program
 Enter A, B, and C values
3 3 3
 This equation has two real roots:
 root 1 =  -0.50000000     +i  0.86602539
 root 2 =  -0.50000000     -i  0.86602539
C:\mydir>
```

Additionally, these results can be verified with a calculator.

8.5 SELECT CASE Statement

A SELECT CASE statement, often referred to as a CASE statement, is used to compare a given value with preselected constants and take an action according to the first constant to match. A CASE statement can be handy to select between a series of different possibilities or cases.

The select case variable or expression must be of type integer, character, or logical. A real type is not allowed. Based on the selector, a set of one or more of Fortran statements can be executed.

The general format of the SELECT CASE statement is:

```
select case (variable)
   case (selector-1)
      <fortran statement(s)-1>
   case (selector-2)
      <fortran statement(s)-2>
      .
      .
      .
   case (selector-n)
      <fortran statement(s)-n>
   case default
      <fortran statement(s)-default>
end select
```

where <fortran statement(s)-1>, <fortran statement(s)-2>, <fortran statement(s)-3>, ..., <fortran statement(s)-n> and <fortran statement(s)-default> are sequences of one or more executable statements. The selector-1, selector-2, selector-3, ..., and selector-n are called selector lists. Each CASE selector list may contain a list and/or range of integers, character or logical constants, whose values may not overlap within or between selectors. A selector-list is either a single or list of values, separated by commas. Each selector list must be one of the following forms.

```
( value )
( value-1 : value-2 )
( value-1 : )
( : value-2 )
```

where value, value-1 and value-2 are constants or literals. The type of these constants must be identical to that of the selector.

- The first form has only one value
- The second form means all values in the range of value-1 and value-2 (inclusive). In this form, value-1 must be less than value-2
- The third form means all values that are greater than or equal to value-1
- The fourth form means all values that are less than or equal to value-2

In order, each selector expression is evaluated. If the variable value is the selector or in the selector range, then the sequence of statements in <fortran statement(s)> are executed.

If the result is not in any one of the selectors, there are two possibilities:

- if CASE DEFAULT is there, then the sequence of statements in statements-DEFAULT are executed, followed by the statement following END SELECT
- if the CASE DEFAULT is not there, the statement following END SELECT is executed

The constants listed in selectors must be unique. The CASE DEFAULT is optional. But with a CASE DEFAULT, you are guaranteed that whatever the selector value, one of the labels will be used. The place for CASE DEFAULT can be anywhere within a SELECT CASE statement; however, putting it at the end would be more natural.

For example, given the declarations,

```
integer :: hours24, hours12
character(2) :: ampm
```

the following case statement,

```
select case (hours24)
      case (0)
            hours12 = 12
            ampm = "am"
      case (1:11)
            hours12 = hours24
            ampm = "am"
      case (12)
            hours12 = hours24
            ampm = "pm"
      case (1:11)
            hours12 = hours24 - 12
            ampm = "pm"
end select
```

might be useful for to convert 24-hour time into 12-hour time.

Additionally, the selectors can be combined and separated by commas. For example, given the declarations,

```
integer :: monthnumber, daysinmonth
character(9) :: monthname
```

the following case statement,

```
select case (monthnumber)
      case (1,3,5,7,8,10,12)
            daysinmonth = 31
      case (2)
            if (mod(year,4)==0) then
                  daysinmonth = 29
            else
                  daysinmonth = 28
            end if
      case (2,4,6,9,11)
                  daysinmonth = 30

      case default
            write (*,*) "Error, month number not valid."
end select
```

might be useful to determine the number of days in a given month. The leap-year calculation is not complete, but is adequate if the range of the year is sufficiently limited.

8.6 Example Two

A typical problem is to assign grades based on a typical grading standard.

8.6.1 Understand the Problem

For this example, the program will assign grades using the following grade scale:

A	B	C	D	F
A>=90	80 - 89	70 - 79	60 - 69	<=59

The program will read three test scores, compute the average, and display the appropriate grade based on the average.

8.6.2 Create the Algorithm

The algorithm is the name for the ordered sequence of steps involved in solving the problem.

For this problem, the variables will be declared and an initial header displayed. Then, the *test1*, *test2*, and *test2* values will need to be read from the user.

```
! declare variables
!     reals -> test1, test2, test2
!     integer -> testave
! display initial header
! read the test1, test2, and test2 values
```

Next, the average can be calculated. The average will be converted to the nearest integer and, based on that, the appropriate grade can be determined and displayed. Formalizing this, the following steps can be developed.

```
! calculate the testave and convert to integer
! determine grade
!         A - >= 90
!         B - 80 to 89
!         C - 70 to 79
!         D - 60 to 69
!         F - <= 59
```

For convenience, the steps are written a program comments.

8.6.3 Develop the Program

Based on the algorithm, the following program can be created.

```
program grades

! declare variables
implicit none
```

```
real :: test1, test2, test2
integer :: testave

! display initial header
      write (*,*) "Grade Assignment Program"
      write (*,*)
      write (*,*) "Enter test 1, test 2 and test 3 values"

! read the test1, test2, and test2 values
      read (*,*) test1, test2, test3

! calculate the average and convert to integer
      testave = nint ((test1 + test2 + test3)/3.0)

! determine grade
!    A → >= 90, B → 80-89, C → 70-79, D → 60-69, F → <= 59

      select case (testave)
            case(90:)
                  write (*,*) "Grade is: A"
            case(80:89)
                  write (*,*) "Grade is: B"
            case(70:79)
                  write (*,*) "Grade is: C"
            case(60:69)
                  write (*,*) "Grade is: D"
            case(:59)
                  write (*,*) "Grade is: F"
      end select

end program grades
```

The indentation is not required, but does help make the program easier to read.

8.6.4 Test/Debug the Program

Once the program is written, testing should be performed to ensure that the program works. The testing will be based on the specific parameters of the program.

In this example, each of the three possible values for the discriminant should be tested.

```
C:\mydir> grade
 Grade Assignment Program

  Enter test 1, test 2 and test 3 values
70 80 90
 Grade is: B

C:\mydir>
```

The program should be tested with a series of data items to ensure appropriate grade assignment for each grade. Test values for each grade should be entered for the testing.

8.7 Exercises

Below are some quiz questions and project suggestions based on this chapter.

8.7.1 Quiz Questions

Below are some quiz questions.

1) List the six relational operators?

2) List the three basic logical operators?

3) For each of the following, answer **.true.** or **.false.** in the space provided.

```
boolean :: b1 = .true., b2=.false., b3=.true.
integer :: i=5, j=10

( b1 .or. b2 )                      _______________

( b1 .or. b3 )                      _______________

( b1 .and. b2 )                     _______________

( b1 .and. b3 )                     _______________

( (b1 .or. b2) .and. b3 )           _______________

( b1 .or. (b2 .and. b3) )           _______________

( .not. ( i < j ) )                 _______________

( j < i )                           _______________
```

4) Write the Fortran IF THEN statement to display the message "Game Over" if the integer variable **`lives`** is $\leq$ to 0.

5) Write the Fortran IF THEN statement to check the integer variable `num` and if the value is < 0, take the absolute value of the number and display the message, "num was made positive".

6) Write the Fortran statements to compute the formula $z=\frac{x}{y}$ assuming the values for integer variables ***x***, ***y***, and ***z*** are previously set. However, if ***y***=0, do not compute the formula, set ***z***=0, and display an error message, "Z not calculated".

7) Write the single IF THEN ELSE IF statement require to compute the following formula using real variables ***f***, ***x***, and ***y***. You may assume the values for ***x*** and ***y*** have been previously set.

$$f(x)=\begin{cases} x^2 * y & \text{if } x \leq 0.0 \\ x * y & \text{if } x > 0.0 \end{cases}$$

8.7.2 Suggested Projects

Below are some suggested projects.

1) Type in the quadratic equation program, compile, and execute the program. Provided input values that will check each of the possible outputs.

2) Write a Fortran program to prompt for and read the year that a person was born. The year must be between 1900 and 2009. If an invalid entry is read, the program should display the message, "Sorry, that is not a valid year." and re-prompt. If the correct value is not provided after 3 attempts, the program should display the message "Sorry, please your having problems." and terminate. Once a valid year is read, the should display the year and a message "is a leap year" or "is not a leap year". Include program statements, appropriate declarations, prompts, read statements, calculations, and write statements. Test the program on a series of input values.

3) Type in the grades program, compile, and execute the program. Test the program on a series of input values that will check each grade.

4) Modify the grades program to handle the following grade assignment;

A	A-	B+	B	B-	C+	C	C-	D	F
>94	93-90	89-87	86-84	83-80	79-77	76-74	73-70	69-60	<59

Compile, and execute the program. Test the program on a series of input values that will check each grade.

5) Write a Fortran program to prompt and read *fahrenheit* as an integer, convert to *celsius*, and display the result as a real. The formula to convert *fahrenheit* to *celsius* is

$$celsius = \left(\frac{5}{9}\right) fahrenheit - 32$$

The *fahrenheit* value must be between -50.0 and 150.0 (inclusive). If the *fahrenheit* value is out of range, the program should display an error message, "Temperature out of range", and re-prompt. If there are 3 invalid temperatures, the program should display "Sorry your having problems." and terminate. The calculations must be performed as real. Include program statements, appropriate declarations, prompts, read statements, calculations, and write statements. Test the program on a series of input values.

6) Write a Fortran to program that reads an item cost (real numbers) and amount tendered (real number) and compute the correct change. The correct change should be returned as the number of twenties, tens, fives, ones, quarters, dimes, nickels, and pennies. The main program should ensure that the amount paid exceeds the item cost and, if not, display an appropriate error message. Test the program on a series of input values.

7) Write a Fortran to program that reads a number from the user that represents a television channel and then uses a CASE construct to determine the call letters for that station.

Channel	Call Letters	Affiliation
3	KVBC	NBC
5	KVVU	FOX
8	KLAS	CBS
10	KLVX	Public
13	KTNV	ABC

The program should display an appropriate message if an invalid or unassigned channel is entered. Test the program on a series of input values that will show each station.

9 Looping

When a series of Fortran statements need to be repeated, it is referred to as a ***loop*** or ***do-loop***. A Fortran ***do-loop*** is a special control statement that allows a Fortran statement or set of statements to be executed multiple times. This repetition can be based on a set number of times, referred to as counter controlled, or based on a logical condition, referred to as conditionally controlled. Each of these looping methods is explained in the following sections.

9.1 Counter Controlled Looping

A counter controlled loop is repeats a series of one or more Fortran statements a set number of times. The general format of the counting loop is:

```
do count_variable = start, stop, step
      <fortran statement(s)>
end do
```

where the count variable must be an integer variable, start, stop, and step are integer variables or integer expressions. The step value is optional. If it is omitted, the default value is 1. If used, the step value cannot be zero. The <fortran statement(s)> is a sequence of statements and is referred to as the *body* of the do-loop. You can use any executable statement within a do-loop, including IF-THEN-ELSE-END IF and even another do-loop. Before the do-loop starts, the values of start, stop, and step are computed exactly once. More precisely, during the course of executing the do-loop, these values will not be re-computed.

The count variable receives the value of start variable or expression. If the value of control-var is less than or equal to the value of stop-value, the <fortran statement(s)> part is executed. Then, the value of step (1 if omitted) is added to the value of control-var. At the end, the loop goes back to the top and compares the values of control-var and stop-value.

If the value of control-var is greater than the value of final-value, the ***do-loop*** completes and the statement following ***end do*** is executed.

For example, with the declarations,

```
integer :: counter, init=1, final=10, sum=0
```

the following do-loop,

```
do counter = init, final
      sum = sum + counter
end do
write (*,*) "Sum is: ", sum
```

will add the numbers between 1 and 10 which will result in 55. Since the step was not specified, it is defaulted 1.

Another example, with the declarations,

```
integer :: counter, init=1, final=10, step=2
```

and the following do-loop,

```
do counter = init, final, step
   write (*,*) counter
end do
```

will display the odd numbers between 1 and 10 (1, 3, 5, 7, 9).

Another example would be to read some numbers from the user and compute the sum and average of those numbers. The example asks the user how many numbers, reads that many numbers, computes the sum, and the computes the average, and displays the results.

```
program average
implicit none
integer :: count, number, sum, input
real    :: average

      write(*,*) "Enter count of numbers to read"
      read(*,*) count

      sum = 0
      do number = 1, count
            read(*,*) input
            sum = sum + input
      end do

      average = real(sum) / real(count)
      write *(*,*) "Average = ", average

end program average
```

The use of the function *real()* converts the sum and count variables from integers to real values as required for the average calculation. Without this conversion, sum/count division would be interpreted as dividing an integer by an integer, yielding an integer result.

A final example of a counter controlled loop is to compute the factorial of a positive integer. The factorial of an integer ***n***, written as ***n***!, is defined to be the product of 1, 2, 3, ..., ***n***-1, and ***n***. More precisely, ***n***! = 1 * 2 * 3 * ... * ***n***.

```
integer :: factorial, n, i

factorial = 1
do i = 1, n
      factorial = factorial * i
end do
```

the above do-loop iterates ***n*** times. The first iteration multiplies factorial with 1, the second iteration multiplies factorial with 2, the third time with 3, ..., the ith time with ***i*** and so on. Thus, the values that are multiplied with the initial value of factorial are 1, 2, 3, ..., ***n***. At the end of the do-loop, the value of factorial is 1 * 2 * 3 * ... * ***n*** which is ***n***!.

9.2 EXIT and CYCLE Statements

The exit and cycle statements are used to modify the execution of a do-loop. The *exit* statement is used to exit a loop. The exit can be used alone, but it is typically used with a conditional statement to allow exiting a loop based on a specific condition. The *exit* statement can be used in a counter controlled loop or a conditionally controlled loop.

For example, given the following declarations,

```
integer :: i
```

the following loop,

```
do i = 1, 10
     if (i == 5) exit
     write(*,*) i
end do
```

will display the numbers from 1 to 4 skipping the remaining iterations. Since the variable ***i*** is checked before the write statement, the value is not displayed with ***i*** is 5 and the loop is exited without completing the remaining iterations.

The *cycle* statement will skip the remaining portion of the do-loop and start back at the top. The *cycle* statement can be used in a counter controlled loop or a conditionally controlled loop. If the cycle statement is used within a counter controlled loop, the next index counter is updated to the next iteration, which could terminate the loop.

9.3 Counter Controlled Example

In this example we will write a Fortran program to find the difference between the sum of the squares and the square of the sum of the first ***N*** natural numbers.

9.3.1 Understand the Problem

In order to find the difference between the sum of the squares and the square of the sum of the first ***N*** natural numbers, we will need to find both the sum of the squares and the square of the sum. For example, the sum of the squares of the first ten natural numbers is,

$$1^2 + 2^2 + \cdots + 10^2 = 385$$

The square of the sum of the first ten natural numbers is,

$$(1 + 2 + \cdots + 10)^2 = 55^2 = 3025$$

Hence the difference between the sum of the squares of the first ten natural numbers and the square of the sum is 3025 - 385 = 2640.

The program will display the ***N*** value, the sum of the squares, the square of the sum, and the difference for each number from 2 to a given ***N*** value. The program should prompt for and read the ***N*** value. The program will display appropriate headers.

9.3.2 Create the Algorithm

For this problem, first we will need to read the ***N*** value. Then, we will loop from 1 to the ***N*** value and find both the sum of the squares and the square of the sum.

```
! declare variables
!     integer -> i, j, n, SumOfSqrs, SqrOfSums
! display initial header
! prompt for and read the n value
! loop from 1 to N
!     compute sum of squares
!     compute sums
! square the sums
! compute difference between sum of squares and square of sums
! display results
```

For convenience, the steps are written a program comments.

9.3.3 Develop the Program

Based on the algorithm, the below program could be developed.

```
program difference

! declare variables
implicit none
integer :: i, n, SumOfSqrs=0, SqrOfSums=0, difference

! display initial header
      write(*,*) "Example Program"
      write(*,*) "  Difference between sum of squares "
      write(*,*) "  and square of sums"
      write(*,*)

! prompt for and read the n value
      write(*,*) "Enter N value: "
      read(*,*) n

! loop from 1 to N

      do i = 1, n
            !     compute sum of squares
            SumOfSqrs = SumOfSqrs + i**2

            !     compute square of sums
            SqrOfSums = SqrOfSums + i
      end do

! square the sums
      SqrOfSums = SqrOfSums**2

! compute difference between sum of squares and square of sums
      difference =  SqrOfSums - SumOfSqrs
```

```
! display results
      write(*,*) "Difference: ", difference

end program difference
```

The spacing and indentation is not required, but helps to make the program more easily readable.

9.3.4 Test/Debug the Program

For this problem, the testing would be to ensure that the results match the expected value. Some expected results can be determined with a calculator or a spreadsheet. If the program does not provided the correct result, one or both of the intermediate results, ***SumOfSqrs*** or ***SqrOfSums***, may be incorrect. These values can be displayed with a temporary write statement to determine which might not be correct. If the problem is still not found, the intermediate values calculated during the loop can also be displayed with a write statement. The output can be reviewed to determine what the program is doing (and what may be wrong).

9.4 Conditional Controlled Looping

A conditional controlled loop repeats a series of one or more Fortran statements based on a condition. As such, the loop may execute a indeterminate number of times.

One form of the conditional loop is:

```
do while (logical expression)
      <fortran statement(s)>
end do
```

In this form, the logical expression is re-checked at the top of the loop on each iteration.

A more general format of the conditional loop is:

```
do
      <fortran statement(s)>
end do
```

As is, this loop will continue forever. Probably not so good. A selection statement, such as an IF statement, and an *exit* statement would be used to provide an means to terminate the looping. For example,

```
do
      <fortran statement(s)>
      if (logical expression) exit
      <fortran statement(s)>
end do
```

Would stop looping only when the logical expression evaluates to true. The exit statement can used used in multiple times in different locations as needed. An IF statement, in any form, can be used for either the exit of cycle statements.

For example, a conditional loop could be used to request input from the user and keep re-prompting until the input is correct.

```
integer :: month

do
      write (*,*) "Enter month (1-12): "
      read (*,*) month
      if (month >= 1 .and. month <= 12) exit
      write (*,*) "Error, month must be between 1 and 12."
      write (*,*) "Please re-enter."
end do
```

This will keep re-prompting an unlimited number of times until the correct input (a number between 1 and 12) is entered.

Since a counter controlled DO loop requires an integer loop counter, another use of conditional loops would be to simulate a real counter. For example, to display the values from 1.5 to 4.5 stepping by 0.25, the following conditional loop could be used.

```
real :: value = 1.5

do
      write (*,*) "Value = ", value
      value = value + 0.25
end do
```

The values and step can be adjusted as needed.

9.5 Conditionally Controlled Loop Example

In this example we will write a Fortran program read a valid date from the user. The date will consist of three values one for each of the month, date, and year. This example will use some of the previous example fragments.

9.5.1 Understand the Problem

For this limited example, we will request a date where the year is between 1970 and 2020. The month must be between 1 and 12. The date will depend on the month since some months have 30 or 31 days. February has either 28 days or 29 days if it is a leap year. Due to the limited allowable range of the year, the determination of a leap year can be performed by checking if the year is evenly divisible by 4 (which implies a leap year).

9.5.2 Create the Algorithm

For this problem, we will need to read the three values (month, date, and year). Then, we will check the values to ensure that date is valid. Then, we will check the month first and then the year since it will be used to check the date. The months January, March, May, July, August, October, and December have 31 days. The months April, June, September, and November have 30 days. February has 28 days unless the years is evenly divisible by 4, in which case February has 29 days.

```
! declare variables; integer -> month, date, year
! display initial header

! loop
!     request month, date, and year
!     read month, date, and year
!     check month (1-12)
!     check year (1970-2020)
!     check date
!           1,3,5,7,8,10,12 → 31 days
!           4,6,9,11 → 30 days
!           2 → if modulo of year/4 is 0 → 29 days
!           2 → if modulo of year/4 is /= 0 → 28 days
! display results
```

For convenience, the steps are written a program comments.

9.5.3 Develop the Program

Based on the algorithm, the below program could be developed.

```
program datecheck

! declare variables
implicit none
integer :: month, date, year, datemax

! display initial header
      write(*,*) "Date Verification Example"

! loop
      do
            ! request month, date, and year
            write(*,*) "Date Verification Example"

            ! read month, date, and year
            read (*,*) month, date, year

            ! check month (1-12)
            if ( month < 1 .or. month > 12 ) then
                  write(*,*) "Error, invalid month"
                  cycle
            end if

            ! check year (1970-2020)
            if ( year < 1970 .or. year > 2020 ) then
                  write(*,*) "Error, invalid year"
                  cycle
            end if

            ! check date
```

```
                    !     1,3,5,7,8,10,12 → 31 days
                    !     4,6,9,11 → 30 days
                    !     2 → if modulo of year/4 is 0 → 29 days
                    !     2 → if modulo of year/4 is /= 0 → 28 days

                    select case (month)
                          case (1,3,5,7,8,10,12)
                                datemax = 31
                          case (2)
                                if (mod(year,4)==0) then
                                      datemax = 29
                                else
                                      datemax = 28
                                end if
                          case (4,6,9,11)
                                datemax = 30
                    end select

                    if ( date < 1 .or. date > datemax ) then
                          write (*,*) "Error, invalid date."
                          cycle
                    end if

                    exit
              end do

        ! display results
              write(*,*) "Valid Date is:", month, date, year

        end program datecheck
```

The spacing and indentation is not required, but helps to make the program more easily readable.

9.5.4 Test/Debug the Program

For this problem, the testing would be to ensure that the results match the expected value. This will require entering a series of different dates and verifying that the displayed output is correct for the given input data.

9.6 Exercises

Below are some quiz questions and project suggestions based on this chapter.

9.6.1 Quiz Questions

Below are some quiz questions.

1) What happen when an *exit* statement is executed?

2) How many *exit* statements can be included in a loop?

3) What happen when an *continue* statement is executed?

4) How many *continue* statements can be included in a loop?

5) If there are multiple *cycle* statements in a loop, which one will be executed?

6) What is the output of the following Fortran statements. Assume ***sum*** and ***i*** are declared as integers.

```
sum = 0
do i = 1, 5
    sum = sum + i
end do
write(*,*) "The SUM is:", sum
```

7) What is the output of the following Fortran statements. Assume ***i*** and ***j*** are declared as integer.

```
do i = 1, 3
    do j = 1, 2
      write(*,*) i, " * ", j, " = ", (i*j)
    end do
end do
write(*,*) "end 2"
```

8) Are the following Fortran statements ***valid*** or ***invalid***? If valid, what will happen?

```
do i = 3, 2
    write(*,*) i
end do

do i = 3, 3
    if ( i == 3 ) then
      write(*,*) i
    end do
end if
```

9) What is the limit of statements that can be included in a loop?

10) When an IF statements (any form) is nested inside a loop, what must be done to ensure the statements are valid?

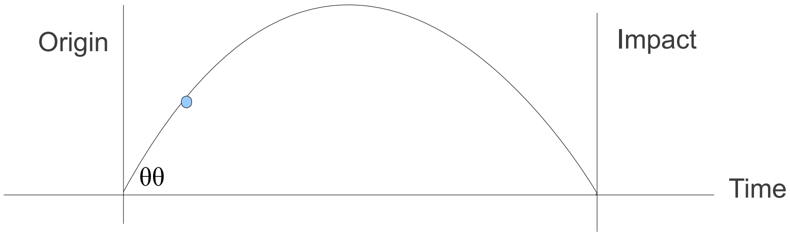
9.6.2 Suggested Projects

Below are some suggested projects.

1) Type in the difference program, compile, and execute the program. Test the program on a series of different input values.

2) Type in the date check program, compile, and execute the program. Test the program on a series of different input values.

3) Write a program to calculate the range that a ball would travel when it is thrown with an initial velocity $\boldsymbol{v_0}$ and angle $\boldsymbol{\theta}$. Based on an initial velocity provided by the user, calculate the range every 5 degrees for angles between 5 and 85 degrees. If we assume negligible air friction and ignore the curvature of the earth, a ball that is thrown into the air from any point on the earths surface will follow a parabolic flight path.



The range (distance between the initial origin and final impact) is determined by the formula:

$$\boldsymbol{range} \; = \; -\frac{2\,v_0^2}{g}\cos\theta\,\sin\theta$$

where $\boldsymbol{v_0}$ is the initial velocity of the ball, θ is the angle of the throw, and $\boldsymbol{g}$ is the acceleration due to the earth's gravity. The value for gravity should be defined as a constant and set to -9.81 meters per second.

Note, the intrinsic trigonometric functions work in radians, so the angle in degrees will need to be converted to radians for the calculations. To convert degrees to radians:

$$\boldsymbol{radians} \; = \; \boldsymbol{degrees}\left(\frac{\pi}{180}\right)$$

Test the program on a series of different input values.

10 Formatted Input/Output

Fortran uses a FORMAT statement to allow control on how data is displayed or read. This is useful when very specific input or output is required. For example, displaying money figures typically require exactly two decimal places. There are format specifiers for each data type; integer, real, character, logical, and complex.

10.1 Format

The format specifiers, separated by commands, are contained in a pair of parenthesis. There are multiple possible ways to define a format. However, we will focus on the easiest, most direct method. The format specifier will replace the second "*" in the read or write statements. For example:

```
read (*,'(<format specifiers>)') <variables>
write (*,'(<format specifiers>)') <variables/expressions>
```

The following sections explain the options for the format specifiers.

10.2 Format Specifiers

The format specifiers tell the system exactly how the input or output should be handled. Each value being read or written requires some amount of space. For example, an integer of four digits requires at least four spaces or positions to print. Therefore, the number of positions to be used is a key part of the specifier.

The following convention of symbols:

w →	the number of positions to be used
m →	the minimum number of positions to be used
d →	the number of digits to the right of the decimal point
n →	the number or count
r →	repeat count

The following is a summary of the most commonly used format specifiers:

Description	Specifier
Integers	***r*I*w*** or ***r*I*w.m***
Real	***r*F*w.d***
Logicals	***r*L*w***
Characters	***r*A** or ***r*A*w***

Horizontal Positioning (space)	***n*X**
Horizontal Positioning (tab)	**T*n***
Vertical Spacing	/

In addition, each specifier or group of specifiers can be repeated by preceding it with a repeat count. Format specifiers for complex numbers will be addressed in later chapters.

10.3 Integer Format Specifier

The integer format specifier ***r*I*w*** or ***r*I*w.m*** is used tell the system exactly how many positions should be used to either read or write an integer variable. The ***w*** is the width or how many total places are used. If the number is negative, the sign uses a place. The ***m*** is optional and can be used to set a minimum number of digits to display, which will display leading zero's if needed in order to display the minimum number of digits. The ***r*** is the number of times the format specifier should be repeated.

A format of '(i6)' would look like:

x	***x***	***x***	***x***	***x***	***x***
←		***w***			→

For example, given the declarations,

```
integer :: num1=42, num2=123, num3=4567
```

the following write statement can be used to display the value in variable *num1* with no leading or trailing spaces.

```
write (*,'(i2)') num1
```

Which will display “42”.

Multiple variables can be displayed. For example, to display the values in variables *num1* and *num2*, with no leading or trailing spaces.

```
write (*,'(i2,i3)') num1, num2
```

Which will display “42123” with no spaces between the two different values. However,

```
write (*,'(i2,i4)') num1, num2
```

will display “42 123” with one space between the values. Further,

```
write (*,'(3(i5))') num1, num2, num3
```

will display “   42 123 4567” where each variable uses 4 spaces.

10.4 Real Format Specifier

The real format specifier ***rFw.d*** is used tell the system exactly how many positions should be used to either read or write an real variable. The ***w*** is the width or how many total places are used, including the decimal point. If the number is negative, the sign uses a place. The ***d*** is how digits are displayed after the decimal point, which does not count the decimal point. The ***r*** is the number of times the format specifier should be repeated.

A format of '(f6.2)' would look like:

x	*x*	*x*	.	*x*	*x*
				← ***d*** →	
← ***w*** →					

For example, given the declarations,

```
real :: var1=4.5, var2=12.0, var3=2145.578
```

the following write statement can be used to display the value in variable *var1* with no leading or trailing spaces.

```
write (*,'(f3.1)') var1
```

Which will display “4.5”. Multiple variables can be displayed. For example, to display the values in variables *var1* and *var2*, with no leading or trailing spaces.

```
write (*,'(f5.2,f8.3)') var1, var2
```

Which will display “ 4.50 12.000” with no leading spaces.

```
write (*,'3(f10.4))') var1, var2, var3
```

Which will display “   4.5000   12.0000 2145.5780” where each variable uses 10 spaces with each having exactly 4 digits after the decimal point.

Although we may print a number using as many positions as you want, this is only for input/output formatting. The number of positions or size is ***not*** the precision (*i.e.*, the number of significant digits) of that number. The default precision of real numbers is about seven significant digits. This is the *precision* of real numbers. However, we can print a real number using 50 positions in which 25 positions are for the fractional part. This is only a way of describing the appearance and does not change the precision of real numbers.

10.5 Logical Format Specifier

The logical format specifier ***rLw*** is used tell the system exactly how many positions should be used to either read or write an logical variable. The ***w*** is the width or how many total places are used. The ***r*** is the number of times the format specifier should be repeated. Since a logical variable can only be set to the logical constants **`.true.`** or **`.false.`** the width will specify how many of the characters logical constants will be read or displayed.

For example, given the declarations,

```
logical :: dooropen=.true., windowopen=.false.
```

the following write statement can be used to display the value in variable *var1* with no leading or trailing spaces.

```
write (*,'(l1,1x,l1)') dooropen, windowopen
```

Which will display “T F”. *Note*, the **l1** format is lower-case L and number 1.

The size or width can be adjusted as needed. For example, the following write statement,

```
write (*,'(l4,2x,l5)') dooropen, windowopen
```

will display “True False” (with two spaces).

10.6 Character Format Specifier

The real format specifier ***rAw*** is used tell the system exactly how many positions should be used to either read or write a character variable. The ***w*** is the width or how many total places are used. If the width is not specified, the existing length of the string is used. The ***r*** is the number of times the format specifier should be repeated.

A format of '(a6)' would look like:

<table>
<tr><td><i><b>c</b></i></td><td><i><b>c</b></i></td><td><i><b>c</b></i></td><td><i><b>c</b></i></td><td><i><b>c</b></i></td><td><i><b>c</b></i></td></tr>
<tr><td colspan="6">← <i><b>w</b></i> →</td></tr>
</table>

For example, given the declarations,

```
character(len=11) :: msg = "Hello World"
```

the following write statement can be used to display the string in variable *msg* with no leading or trailing spaces.

```
write (*,'(a7)') msg
```

Which will display “Hello World”. Multiple variables or strings can be displayed. For example, to display the string in variable *msg* and the string “Good bye cruel world”.

```
write (*,'(a7,2x,a)') msg, "Good bye cruel world"
```

Which will display “Good bye cruel world” to the screen.

10.7 Advance Clause

The advance clause instructs the computer whether or not to advance the cursor to the next line. The possible values are “yes” and “no”. If the advance clause is not included, the default value is “yes”. This clause can is useful when prompting for user input to allow the input to be entered on the same line as the prompt.

For example, the period program from the previous chapter included the statements:

```
! prompt for and read the n value
      write(*,*) "Enter N value: "
      read(*,*) n
```

Which, when executed, the input is entered on the line following the prompt.

```
c:\mydir> sums
 Example Program
   Difference between sum of squares
   and square of sums

 Enter count of numbers to read:
3
 Difference:         2640
```

When the advance clause is included, with the setting of “no” as follows:

```
! prompt for and read the n value
      write(*,*, advance="no") "Enter N value: "
      read(*,*) n
```

The resulting execution would be as follows:

```
c:\mydir> sums
 Example Program
   Difference between sum of squares
   and square of sums

 Enter count of numbers to read: 10
 Difference:         2640
```

Which allows the input to be entered on the same line as the prompt.

10.8 Example

This example will read a date from the user (month, date, and year, on the same line), determine the day of week (for that month/date/year). Then, the program will display the original input date (numeric form) and the formatted date. The original input date will be displayed include leading 0's (i.e., 01/01/2010).

10.8.1 Understand the Problem

For this problem, we will read the three numbers for the date from the user. The verification of the date information is left as an exercise.

To calculate the day on which a particular date falls, the following algorithm may be used (the divisions are integer divisions):

```
a = (14 - month) / 12
y = year - a
m = month + 12*a - 2
daynum = [ date + y + y/4 - y/100 + y/400 + (31*m/12) ] mod 7
```

The value of ***daynum*** is 0 for a Sunday, 1 for a Monday, 2 for a Tuesday, etc.

10.8.2 Create the Algorithm

For this problem, first we will need to read the date. The verification of the date entered and error checking is left as an exercise. Then, the original input date can be displayed, in numeric form, formatted appropriately. For a date, this would mean two digits for the month, a "/", two digits for the date, a "/", and four digits for the year. When the date is only one digit, for example 5, it is customary to display a "05" so the program will ensure this occurs.

```
! declare variables
!     integer -> month, date, year
! display initial header
! prompt for month, date, and year
! read month, date, and year
! display formatted numeric month/date/year
```

Then the program can calculate the day of the week (based on the formula) and convert the resulting number (0-6) into a date string and display the result.

```
! calculate day of week
! convert day of week (0-6) to string
! convert month (1-12) to string
! display formatted string for day, month, and year
```

For convenience, the steps are written a program comments.

10.8.3 Develop the Program

Based on the algorithm, the below program could be developed.

```
program dateformatter

! declare variables
implicit none
integer :: month, date, year
integer :: a, m, y, d,
character(9) :: amonth, day_of_week

! ----------
! display initial header
      write(*,*) "Date Formatting Example"
```

```
! prompt for  month, date, and year
      write(*,*,advance="no") "Enter date (month, date, year):"

! read month, date, and year
      read (*,*) month, date, year

! ----------
! display formatted numeric month/date/year

      write(*,*) "----------------------------------------"
      write(*,*) "Input Date: "
      write(*,'(5x, i2.2, a, i2.2, a, i4)', imonth, "/",   &
      idate, "/", iyear

! ----------
! calculate day of week

      a = (14 - imonth) / 12
      y = iyear - a
      m = imonth + 12 * a - 2
      d = mod ( (idate + y + y/4 - y/100 + y/400 + (31*m/12)), 7)

! ----------
!     convert day-of-week integer to day-of-week string

      select case (d)
            case (0)
                  day_of_week = "Sunday   "
            case (1)
                  day_of_week = "Monday   "
            case (2)
                  day_of_week = "Tuesday  "
            case (3)
                  day_of_week = "Wednesday"
            case (4)
                  day_of_week = "Thursday "
            case (5)
                  day_of_week = "Friday   "
            case (6)
                  day_of_week = "Saturday "
      end select

! ----------
! convert month (1-12) to string

      select case (month)
            case (1)
                  amonth = "January  "
            case (2)
                  amonth = "February "
            case (3)
                  amonth = "March    "
            case (4)
                  amonth = "April    "
            case (5)
                  amonth = "May      "

            case (6)
                  amonth = "June     "
            case (7)
                  amonth = "July     "
            case (8)
                  amonth = "August   "
            case (9)
                  amonth = "September"
            case (10)
                  amonth = "October  "
            case (11)
                  amonth = "November "
            case (12)
                  amonth = "December "
      end select

! ----------
! display formatted string for day, month, and year

      write(*,'(/a)') "Formatted Date:"
      write(*,'(5x, a, a, a, 1x, i2.0, a, i4/)')                       &
                  trim(day_of_week), ", ", trim(smonth),        &
                  idate, ", ", iyear

end program dateformatter
```

The spacing and indentation is not required, but helps to make the program more easily readable. The *trim()* intrinsic function removes any trailing spaces from the input string. Additional information regarding handling character data types in provided in the following section.

10.8.4 Test/Debug the Program

For this problem, the testing would be to ensure that the output formatting is correct. Since there is no error checking on the input, only correct dates should be entered. Test the program on a series of different input values and verify that the output is correct for those input values.

10.9 Exercises

Below are some quiz questions and project suggestions based on this chapter.

10.9.1 Quiz Questions

Below are some quiz questions.

1) What is the format specifier for each of the following:
   a) integer values
   b) real values
   c) logical values
   d) horizontal spacing (i.e., spaces)

e) a newline
f) characters/strings

2) Describe the output of the following code fragment (1 pts each):
Note, show blanks with an _ (underscore) character.

```
write (*,'(a5)') "Hello World"
write (*,'(a)') "Hello World"
```

3) Describe the output of the following code fragment (3 pts):
Note, show blanks with an _ (underscore) character.

```
integer :: number = 5
write (*,'(i5.3)') number
```

4) What is the write statement and format specifier to output the integer variable ***num1*** which contains an value between 0 and 999 (right justified, no leading zero's, no additional spaces).

5) What is the write statement and format specifier to output the real value of ***pi*** which has been initialized to 3.14159 (right justified, no additional spaces)?

6) What is the *single* write statement and format specifier to output "Programming" and "Is Fun!" on two different lines?

7) What is the single write statement and format specifier to output "Enter Number:" and leave the cursor on the current line?

10.9.2 Suggested Projects

Below are some suggested projects.

1) Type in the date formatting program example, compile, and execute the program. Test the program on a series of different input values and verify that the output is correct for those input values.

2) Update the date formatting program to perform complete error checking on the date entered. That is, the program should check for appropriate values for month (between 1 and 12), check for appropriate values for date (between 1 and 31), including checking for a valid date for the specific month, and ensure that the value for year is between 1970 and 3000 (inclusive). For example, April 31 is not a valid date. Additionally, the program should check for a leap year to see if February has 28 or 29 days for that year. Test the program on a series of different input values and verify that the output is correct for those input values.

3) Write a Fortran program that displays an amortization schedule. The program should read the loan amount, annual interest rate, and the loan term in months (from a single line).

   The formula for calculating the monthly payment is:

$$\boldsymbol{payment} \;=\; \boldsymbol{amount} * \left(\boldsymbol{irate} * \frac{(1+\boldsymbol{irate})^{term}}{(\,(1+\boldsymbol{irate})^{term} - 1)} \right)$$

   Note, the *irate* in the formula must be converted to a monthly rate (divided by 12) and then divided by 100 (to convert from percentage). During the time period (term), some of each monthly payment will be used to pay the interest and some will be used to reduce the outstanding balance. The monthly interest amount can be calculated by monthly interest rate times outstanding balance. The amounts must be lined up with only two digits for cents. The payment number must three digits (including leading zero's if necessary). Test the program on a series of different input values and verify that the output is correct for those input values.

4) Write a Fortran program that calculates and displays compounded interest. The program should read the initial principal amount, interest rate percentage, and the term (number of years). The program should display a summary of the input and the yearly compounded interest. Refer to the example output for formatting.

   The formula for compounding interest is:

$$\boldsymbol{value} \;=\; \boldsymbol{principal}(1+\boldsymbol{interest})^{year}$$

   Note, the interest rate percentage read form the user must be converted to a number (i.e., divided by 100). The output must be formatted in a manner similar to the example output. This includes ensuring that the dollar amounts are displayed with the appropriate two decimal points. Test the program on a series of different input values and verify that the output is correct for those input values.

11 Characters and Strings

Fortran was originally developed for scientific and engineering application requiring significant mathematical calculations. However, the Fortran 95 language includes extensive character and string handling capabilities.

11.1 Character and String Constants

A character is a single character or symbol, typically enclosed in quotes. For example, letters ("A"-"Z" and "a" - "z"), punctuation ("!", ",", "?", etc.) , symbols, ("@", "#", ">", etc.), and digits "1", "2" are characters.

Some examples include:

```
"X"
"z"
"5"
```

Character and string constants are case sensitive. So, character "X" (upper-case) is not the same as "x" (lower-case). When a digit is enclosed in quotes, it is treated as a character and consequently arithmetic operations (addition, subtraction, etc.) are not allowed.

A string is a series of characters. A string consists of an arbitrary sequence of characters also enclosed in quotes. Some examples include:

```
"Hello World."
"456"
"1 2 3"
"456?"
"Good bye cruel world!!"
"Have a nice day?"
```

Since digits enclosed in quotes are not numeric values, the strings "1 2 3" and "456?" are allowed.

A problem arises if you want to have a quote in the string itself. A double quote will be interpreted as a single within a string.

```
"He said ""wow"" when he heard"
```

The double-quoting is sometimes referred to as an escape character. Strings and characters must be associated with the character data type.

11.2 Character Variable Declaration

A character variable is a variable that can contain a set of 1 or more characters. Character variables must have a defined length. All declarations are placed in the beginning of the program (after the program statement). Declaring character variables formally defines the type and sets aside memory.

This is performed with a type declaration statement in the form of:

```
<type> :: <list of variable names>
```

For character variables, the type is "character". For example, to define an character variable to hold the day of week (i.e., "Wednesday"), the following declaration,

```
character(len=9) :: dayofweek
```

Would define the variable, *dayofweek*, with a maximum length of 9 possible characters.

Additional examples include:

```
character(len=3) :: symbol1, symbol2
character :: symbol3
character(1) :: symbol5, symbol5
character(30) :: symbol6, symbol7
```

The declarations can be entered in any order, however they must be at the beginning of the program.

The "len=" is optional and can be omitted. When the length is omitted entirely, the default length is set to 1. This, "character", "character(len=1), and "character(1)" are all the same.

When multiple variables are included in a single declaration, they must all be the same length. If different lengths are required, separate declaration lines are required.

11.3 Character Variable Initialization

It is possible to declare a character variable and to set it is initial value at the same time. This initialization is not required, but can sometime be convenient. For example, to define an character variable, *dayofweek*, and set it to a day of week:

```
character(len=9) :: todaysdate="Wednesday"
```

Additional examples include:

```
character(9) :: thismonth="June", lastmonth, nextmonth="July"
character :: ltr1="A", ltr2="b"
```

Spaces or no spaces between the variables, equal signs, semicolons, and commas are allowed. Variables initialized at declaration can be changed during program execution as needed.

11.4 Character Constants

It is possible to declare a character variable, set it is initial value, and ensure that the value can not be changed. For example, to define an character constant, *lang*,

```
character(len=7), parameter :: lang="English"
```

To save counting the characters, the "*" can be used. For example,

```
character(len=*), parameter :: university="UNLV"
```

This instructs the Fortran compiler to count the characters and set the appropriate length.

11.5 Character Assignment

Assignment is term for setting a character variable equal to some value (character or string). Assignment is performed with a equal (=) sign. For example, given the declaration,

```
character(9) :: thismonth
```

A value can be assigned to the variable as follows,

```
thismonth = "September"
```

When character variables are assigned they are filled from the left and automatically padded with blanks if necessary. For example, if the variable *thismonth* is reset

```
thismonth = "May"
```

The variable *thismonth* contains “May   ” (i.e., “May” with an additional 6 blanks).

11.6 Character Operators

The only character operator is “//” (concatenation) which simply concatenates two strings together. For example,

```
"University of" // "Nevada Las Vegas"
```

Characters variables and literals may be used with concatenation. For example, given the following declaration,

```
character(len=6) :: str1="ABCDEF", str2="123456"
character(len=12) :: str3
```

The following statements

```
str3 = str1 // str2
```

will set *str3* to “ABCDEF123456”.

11.7 Character Substrings

A substring is a subset of a string. A substring can be selected based on the characters position or count within the start with the first character corresponding to 1 and the second character corresponding to 2 as so forth for as many characters are in the entire string. The substring is specified with a start and stop position in the form of (start:stop). The stop must be greater than or equal to the stop position.

For example, given the following declaration,

```
character(len=6) :: str1="ABCDEF", str2="123456", str3
```

The following statements

```
str3 = str1(1:3) // str2(4:6)
```

will set *str3* to “ABC456”.

11.8 Character Comparisons

The standard relational operators ("==", ">", ">=", etc.) have some limitations when character data is used. Simple comparisons, such as,

```
"A" < "D"
"ABC" == "ABC"
```

will work as expected. That is, both will evaluate to true.

However, when comparing, the following characters,

```
"A" > "a"
"100" < "20"
"ABC" <= "ABCD"
```

each will evaluate to false.

This is a result of the relational operations referring to the assigned values (based on their location in the ASCII table located in Appendix A).

Comparisons between digits, "0" - "9", will work relative to each other. Comparisons between upper-case letters, "A" - "Z", will also work relative to each other. Comparisons between lower-case letters, "a" - "z", will also work relative to each other. Since the lower case letters are after the upper case letters in the table an upper-case letter will be greater than a lower-case letter. The digits are in the table before letters (upper and lower-case), so they will evaluate as less than letters. This must be taken into account when dealing with character comparisons.

11.9 Intrinsic Character Operations

There are a number of character oriented intrinsic operations. Some of the basic character oriented functions include:

Function	Description
ACHAR(I)	Returns the character represented by integer argument I based on the ASCII table (Appendix A). Integer argument I must be between 1 and 127.
IACHAR(C)	Returns the integer value of the character argument C represented by ASCII table (Appendix A).
LEN(STR)	Returns an integer value representing the length of string argument STR.
LEN_TRIM(STR)	Returns an integer value representing the length of string argument STR excluding any trailing spaces.
TRIM(STR)	Returns string based on the string argument STR with any trailing spaces removed.

A complete list of intrinsic functions can be found in Appendix D.

11.10 Example

This example will scan a string and convert all lower-case letter to upper-case.

11.10.1 Understand the Problem

For this problem, the string will be read from the user with a maximum of 80 characters. Any lower case letters encountered will be converted to upper-case. All other characters (digits, symbols, etc.) will be left alone. To determine if a characters is lower-case, we can see if it is between “a” and “z”. The final string will be displayed back to the screen. Based on the ASCII table in Appendix A, there is a specific, fixed difference between each upper and lower-case letter. Thus, in order to convert a lower-case character to upper-case, that difference can be subtracted. However, in order to perform the subtraction, each character needs to be converted into an integer (based on its value in the ASCII table). The IACHAR() intrinsic function performs this conversion. After the conversion (subtraction), the integer must be converted back into its corresponding character, which can be accomplished with the ACHAR() intrinsic function. These functions work on a single character/integer, so each character will need to be addressed individually.

11.10.2 Create the Algorithm

For this problem, first we will need to prompt for and read the input string. Then any trailing blanks will be removed and the final length can be determined. Based on that length, each character will be accessed and converted if needed.

```
! declare variables
!     integer -> string1, string2, I, strlen
! display initial header
! prompt for string
! read string
! trim any trailing blanks
! determine length of string
! loop
!     access each character
!     if check lower-case ("a" – "z") -> convert to upper-case
! display final string
```

For convenience, the steps are written a program comments.

11.10.3 Develop the Program

Based on the algorithm, the below program could be developed.

```
program caseconverter

! declare variables
implicit none
integer :: i, strlen
character(80) :: string1
```

```
! ----------
! display initial header
      write(*,'(a,/)') "Case Conversion Example"

! ----------
! prompt for string
! read string
      write(*,'(a)',advance="no") "Enter String (80 char max): "
      read (*,'(a)') string1

! ----------
! trim any trailing blanks
! determine length of string
      strlen = len(trim(string1))

! loop
      do i = 1, strlen

      !     access each character
      !     if check lower-case -> convert to upper-case

      if ( string1(i:i) >= "a" .and. string1(i:i) <= "z" ) then
            string1(i:i) = achar( iachar(string1(i:i)) - 32)
      end if

      end do

! ----------
! display final string

      write(*,'(/,a)') "-------------------------------------"
      write(*,'(a,/,2x,a,/)') "Final String: ", string1

end program caseconverter
```

The spacing and indentation is not required, but helps to make the program more easily readable.

11.10.4 Test/Debug the Program

For this problem, the testing would ensure that the output string is correct for the given input.

For example, the following output,

```
c:\mydir> case
Case Conversion Example

Enter String (80 char max): Hello World!?

-------------------------------------
Final String:
  HELLO WORLD!?
```

Each lower-case letter was converted to upper-case while the upper-case, space, and punctuation were unchanged. The program should be executed with a series of test inputs to verify the correct output.

11.11 Exercises

Below are some quiz questions and project suggestions based on this chapter.

11.11.1 Quiz Questions

Below are some quiz questions.

1) What is the declaration for a character variable to contain the string "Hello World"?

2) Given the following relational expressions,

```
"D" > "c"
"100" < "20"
"Da" > "cA"
"20" < "10"
"d" > "C"
"20" < "100"
"ABBC" <= "ABCD"
```

   state which will evaluate to true and which to false.

3) Given the following Fortran statements,

```
character(len=*) :: str1="abcdef", str2="ABCDEF"
character(len=*) :: str3="123456", str4="78910"
character(len=12) :: astr1, astr2, astr3, astr4

astr1 = str1(1:3)
astr2 = str3(4:6)
astr3 = str3 // str4
astr4 = str2(4:6) // str3(1:3) // str1(2:3)
```

   provide the resulting strings (astr1 – astr4).

4) How can the integer value (based on the ASCII table) of a character be obtained?

5) How can integer value be converted to a character (based on the ASCII table)?

11.11.2 Suggested Projects

Below are some suggested projects.

1) Type in the case conversion example program example, compile, and execute the program. Test the program on a series of different input values and verify that the output is correct for those input values.

2) Update the case conversion example program to convert any upper-case characters to lower-case characters. Test the program on a series of different input values and verify that the output is correct for those input values.

3) Write a program to read a string and count the vowels ("a", "e", "i", "o", and "u"). The program should provided a count for each vowel and a total count of vowels. The program should ensure that the vowels are counted for both upper and lower-case. Test the program on a series of different input values and verify that the output is correct for those input values.

4) Write a program to read 5 strings (≤ 80 characters each) and display the strings in alphabetical order. Test the program with a variety of different input strings, including digits, upper-case, and lower-case characters. Test the program on a series of different input values and verify that the output is correct for those input values.

12 File Operations

File operations allow Fortran programs to read from files and/or write to files. The basic read and write statements for file operations are the same as previously used with some additional information or clauses.

12.1 File Open

A file must be opened before information can be written or read from a file. In order to open a file, the operating system needs some information about the file in order to correctly identify the file and establish the access parameters (i.e., read, write, etc.). The open statement "clauses" is how is information is provided.

The file open statement is as follows:

```
open (unit=<unit number>, file=<file name>,                    &
            status=<file status>, action=<file action>,         &
            position=<file position>, iostat=<status variable>)
```

The following table summarizes the various open statement clauses.

Clause	Explanation
unit	Unit number for subsequent file operations (i.e., read, write, etc.). Typically an integer between 10 and 99.
file	Name of file to be opened. Can be quoted or a character variable.
status	Status of file. Allowable options "old", "new", or "repalce" "old" → the file must already exist. "new" → a new file will be created. "replace" → a new file will be created, replacing an existing one if necessary.
action	Action or open operation. Allowable options are "read", "write", or "readwrite". "read" → read data from a file. "write" → write data to a file. "readwrite" → simultaneously read data from and write data to a file.
position	Position or place to start. Allowable options are "rewind" (beginning), "append" (end).

iostat	Name of variable for system to place a status code indicating the status (success or failure) of the operation. If the status variable is set to 0, the operation is successful. If the status variable is set to >0, an error occurred and the operation was unsuccessful.

The unit number assigned should be between 10 and 99.

12.2 File Write

The file must be opened for “write” or “readwrite” access before any information can be written to the file. The general form of the write statement is as follows:

```
write (unit=<unit number>, fmt=<format statement>,              &
                  advance="no", iostat=<variable>)              &
                        <variables/expressions>
```

The write is the same as the simple write, however the unit number must be the number assigned during the open operation. Normally, the next write will be on the next line. The “advance=”no”” is optional. If it is included, the next write will be on the same line where the previous line stopped.

For example to open a file named temp.txt and place the string “Fortran Example” and the numbers 42, and 3.14159 on separate lines, the following declarations:

```
integer :: myanswer=42, myopenstatus, mywritestatus
real, parameter :: pi=3.14159
character(15) :: mymessage="Fortran Example"
character(8) :: myfilename="temp.txt"
```

and the following Fortran statements,

```
open (unit=10, file=myfilename, status="replace",               &
            action="write",   position="rewind",                &
            iostat=myopenstatus)
if (myopenstatus > 0) stop "Can not open file."
write(10, '(a/, i5/, f7.5)', iostat=mywritestatus)              &
                                   mymessage, myanswer, pi
```

would write the file information to the file.

12.3 File Read

The file must be opened for “read” or “readwrite” access before any information can be read from the file.

The general form of the write statement is as follows:

```
read (unit=<unit number>, fmt=<format statement>,              &
            iostat=<variable>) <variables/expressions>
```

The read is the same as the simple read, however the unit number must be the number assigned during the open operation. If the status variable is set to less than 0, that is an indication that the end of the file has been reached.

For example, if the file numbers.dat exists and has two numbers (on separate lines), the following declarations,

```
integer :: num1, num2, myopenstatus, myreadstatus
character(11) :: myfilename="numbers.txt"
```

and the following Fortran statements,

```
open (unit=12, file=myfilename, status="old",                  &
            action="read",   position="rewind",                &
            iostat=myopenstatus)
if (myopenstatus > 0) stop "Can not open file."

read(12, '(i5)', iostat=myreadstatus) num1
read(12, '(i5)', iostat=myreadstatus) num2
```

would write the file information to the file.

12.4 Rewind

An open file can be reset back to the beginning. This might be useful if the file needs to be read twice. The rewind statement will reset the file read pointer and subsequent reads will start back at the beginning. The general form of a rewind statement is:

```
rewind(<unit number>)
```

Where the the unit number was assigned during the initial open. The file must be open for the rewind to work correctly.

12.5 Backspace

When reading from a file, each successive read will return the next line from the file. The computer keeps track of which lines have been read and will automatically return the next line. It is possible to read a line and then backspace and re-read the line again with the backspace statement.

The general form of a backspace statement is:

```
backspace(<unit number>)
```

Where the the unit number was assigned during the initial open. The file must be open for the backspace to work. This is not used very often.

12.6 Close File

An open file should be closed when it is no longer needed. The general form of a close statement is:

```
close(<unit number>)
```

Where the the unit number was assigned during the initial open.

For the previous examples,

```
close(10)
close(12)
```

would be used to close the opened files.

12.7 Example

In this example we will write a Fortran program to read an input file and write a line number and the original line to an output file.

12.7.1 Understand the Problem

For this problem, we will read get the file names from the user and open the files. Then we will read a line from the input file, and write the line number and line to the output file. When done, we will close the file.

12.7.2 Create the Algorithm

For this problem, first we will need to prompt for and read the file names from the user and ensure that they open correctly. If the file can not be opened, an error message will be displayed and the file names will be re-read.

```
! declare variables
!     integer -> i, rdopst, wropst
!     character -> line
! display initial header
! loop
!     prompt for input file name
!     read input file name
!     open input file (read access)
!     if open unsuccessful, display error message
!     otherwise, end loop
! loop
!     prompt for output file name
!     read output file name
!     open output file (write access)
!     if open unsuccessful, display error message
!     otherwise, end loop
```

Once the file is open, a line will be read from the input file, and the line number and the line will be written to the output file. For this example, we will assume that a line will have 132 or less characters. This process will continue until there are no more lines in the input file.

```
! loop
!     read line from input file
!     if end of file, exit loop
!     write line number and line to output file
! close files
```

For convenience, the steps are written a program comments.

12.7.3 Develop the Program

Based on the algorithm, the below program could be developed.

```
program linenumbers

! declare variables
implicit none
integer :: i, rdopst, wropst, rdst
character(30) :: rdfile, wrfile
character(132) :: line

! display initial header
      write(*,*) "Line Number Example"

! ----------
! prompt for input file name
      do
            write(*,'(a)', advance="no") "Input File Name: "

            ! read input file name
            read(*,*) rdfile

            ! open input file (read access)
            ! if open unsuccessful, display error message
            !     otherwise, end loop
            open(12, file=rdfile, status="old",                  &
                        action="read", position="rewind",        &
                        iostat=rdopst )
            if (rdopst==0) exit

            write(*,'(a/,a)') "Unable to open input file.",      &
                              "Please re-enter"
      end do

! ----------
! prompt for output file name
      do
            write(*,'(a)', advance="no") "Output File Name: "

            ! read output file name
            read(*,*) wrfile

            ! open output file (read access)
            ! if open unsuccessful, display error message
            !     otherwise, end loop

            open(14, file=wrfile, status="replace",            &
                        action="write", position="rewind",     &
                        iostat=wropst )
            if (wropst==0) exit

            write(*,'(a/,a)') "Unable to open output file.",   &
                              "Please re-enter"
      end do

! ----------

      i = 1
      do
            ! read line from input file
            read(12, '(a)', iostat=rdst) line

            ! if end of file, exit loop
            if (rdst >0) stop "read error"
            if (rdst <0) exit

            ! write line number and line to output file
            write(14, '(i10,2x,a)') i, line
            i = i + 1
      end do

! close files
      close(12)
      close(14)

end program linenumbers
```

The spacing and indentation is not required, but helps to make the program more easily readable.

12.7.4 Test/Debug the Program

For this problem, the testing would involve executing the program with various input files and verifying that the line numbers are correctly added.

12.8 Exercises

Below are some quiz questions and project suggestions based on this chapter.

12.8.1 Quiz Questions

Below are some quiz questions.

1) What must occur before a file can be read or written?

2) What is the range of the valid unit numbers for a file open?

3) For the following statements:

```
integer :: opnstat
character(20) :: filename="file.txt"

open (14, file=filename, status="old", action="read",           &
      position="rewind", iostat=opnstat)

if ( opnstat > 0 ) then
      write (*, *) "Error, can not open file."
      stop
end if
```

a) What is the name of the file being opened?

b) What is the *unit* number that will be used for subsequent write operations?

c) Does the error message get printed if the file does not exist (yes/no)?

d) What does it mean when the status variable is > 0?

4) Assume the file **`answers.txt`** exists and contains:

```
"line 1 data1=23 data2 = 34 data3 = 5123"
```

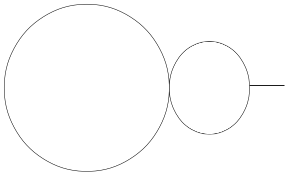
What is the read statement required to get data1, data2, and data3 into the integer variables ***num1***, ***num2***, and ***num3*** respectively.

12.8.2 Suggested Projects

Below are some suggested projects.

1) Type in the line numbers program, compile, and execute the program. Test the program on a number of different input values.

2) Imagine the movement of a small circle that rolls on the outside of a rigid circle. Imagine now that the small circle has an arm, rigidly attached, with a plotting pen fixed at some point. That is a epicycloid, commonly called a spirograph[7]. Write a Fortran 95 program to generate the (x,y) coordinates for a spirograph drawing.



First, the program should prompt for an output file name, read the file name, and open the file.

[7] For more information, refer to: http://en.wikipedia.org/wiki/Spirograph

If the file can not be opened, the program should display an appropriate error message and re-prompt. Next, the program should prompt for a read radius 1 (fixed circle), radius 2 (moving circle), offset position (rigid arm length). The radius 1, radius 2, and offset position values must be between -100 and +100 (inclusive). If any value is out of range, the program should re-prompt. If the user does not enter a valid file name or number of input values after three tries, the program should terminate with an appropriate error message. That is, three errors are acceptable, but if a fourth error is made, the program should terminate. The prompts and subsequent reads should be on the same line (see example).

Then, the program should generate (x,y) points based on one the following formulas:

$$x=((radius_1+radius_2) * \cos(step)) + \left(offsetposition * \cos\left((radius_1+radius_2) * \frac{step}{radius_2} \right) \right)$$

$$y=((radius_1+radius_2) * \sin(step)) + \left(offsetposition * \sin\left((radius_1+radius_2) * \frac{step}{radius_2} \right) \right)$$

The step should start at 0.0 and stop at 360.0, stepping by 0.1. All writes should use a formatted output (not the '*'). Then the program should close the output file, inform the user the plotting is completed. Test the program on a number of different input values.

3) Write a Fortran program that plays the Chaos Game. To play the Chaos Game, plot 3 points A, B, C and an arbitrary initial point X1. Then, generate a random number between 1 and 3 representing A, B, or C. If A comes up, plot the midpoint of the line joining X1 to A. If B comes up, plot the midpoint of the line joining X1 to B; the case with C is similar. Call this new point X2. Roll the die again. Plot the midpoint of the line joining X2 to either A, B or C depending on the outcome of the die toss. Call this new point X3. Repeat this process N times. Test the program on a number of different input values.

Note, the correct output of this program is shown on the cover page.

13 Single Dimension Arrays

An array is a collection or set of data. A variable can hold a single value. An array can hold multiple values. The type (i.e., integer, real, etc.) of each item in the array must be the same. In order to access specific elements an *index* or *subscript* is used. The index specifies which element or value in the array.

An array is consider a direct access structure since any element can be accessed directly, without accessing any other elements.

The most basic form of an array is a single dimension array. A single dimension array can be thought of as a single column in a spreadsheet. The column name, like ***A***, is the array name and the row number is like the index.

For example, a single dimension array might look like:

	index	value
Array Name	1	<value>
	2	<value>
	3	. . .
		. . .
		<value>
	n	<value>

The specific syntax requires an index or subscript to specify which element of the array to access. By default, the first element is at index=1, the next at index=2, and so forth. This can be changed if needed.

13.1 Array Declaration

An array must be declared before use. The type of the array is defined followed by the size or dimension. There are two ways to declare an array; static and dynamic.

13.1.1 Static Declaration

A static declaration means that the size or dimension of the array must be defined initially (before the program is compiled). The size definition can not be altered. The general form an array declaration is,

```
type, dimension(extent) :: name1, name2, …, nameN
```

where type is the data type (integer, real, etc.) of the array. The dimension specifies the the extent or size, and ***name1***, ***name2***, …, ***nameN*** are names of one or more arrays being declared.

For example, to declare an array of 1000 integers,

```
            integer, dimension(1000) :: nums1
```

will create an array, ***nums1***, with space for 1000 integer values.

In this example the extent is 1000 which means that the array indexes will range form 1 to 1000. The extent can be changed by specifying the extent as:

```
            smaller-integer :: larger-integer
```

When only one number is specified, the smaller-integer is assumed to be 1. When both numbers are specified, the array index's will range between the smaller-integer and the larger-integer. For example, a declaration of:

```
            integer, dimension(-5:5) :: ranges
```

will create an array, ranges, with indexes between -5 and 5 (inclusive). Using index values not within the specified range will result in an error.

13.1.2 Static Array Declaration

Static array declarations are appropriate when the maximum size of the array is known ahead of time. Once the array is declared, the size can not be extended. A static array is initialized and the size of set during the declaration. For example, to declare an array named costs with 4 elements and set the four elements to 10.0, 15.0, 20.0, and 25.0,

```
            real, dimension(4) :: costs=(/10.0, 15.0, 20.0, 25.0/)
```

The numbers, enclosed between the "/"s are assigned in order. So, costs(1) is set to 10.0, costs(2) is set to 15.0, costs(3) is set to 20.0, and costs(4) is set to 25.0.

Additionally, after declaration, it is possible to initialize all elements of an array to a single value with an assignment statement. For example,

```
            costs = 0
```

will set all four elements of the costs array to zero.

13.1.3 Dynamic Array Declaration

A dynamic declaration means that the size or dimension of the array can be set when the program is executed. Dynamic array declarations are appropriate when the maximum size of the array is not known ahead of time and can be determined based on information obtained when the program is executing. However, once set, the size can not be altered. When using a dynamic declaration, the array type and name must be defined. This only specifies the name and type of the array, but does not reserve any space for the array. During the program execution, the array must be allocated. The allocation will create the space for the array. Only after the array has been allocated can it be used.

For example, to declare an array,

```
            integer, dimension(:), allocatable :: nums2
```

reserving the name ***nums2***, but not reserving any space for values.

13.1.3.1 Dynamic Array Allocation

To allocate the space for the array, the allocate statement must be used. Before an array can be allocated, it must be declared as allocatable. The general form of the allocate statement is:

```
            allocate(<array name>, stat=<status variable>)
```

The status variable must be an integer variable and will be used by the system to place a status code indicating the status (success or failure) of the operation. If the status variable is set to 0, the allocation was successful. If the status variable is set to >0, an error occurred and the allocation was not unsuccessful.

For example, given the declarations,

```
            integer, dimension(:), allocatable :: nums2
            integer :: allst
```

the following allocate statement allocates space for 1000 numbers in array nums2,

```
            allocate(num2(1000), stat=allst)
```

The size, 1000 in this example, can be a variable, but it must be an integer. The variable *allst* will be set to 0 if the allocation is successful and >0 if the allocation failed.

13.2 Accessing Array Elements

To access elements in an array, the array name and the an index must be specified. The index is must be an integer or integer expression and enclosed in parentheses. The general format is,

```
            array-name(<integer expression>)
```

For example, given the declaration,

```
            real, dimension(10) :: times
```

would declare an array with ten elements. To place a value 121.3 in the first array element,

```
            times(1) = 121.3
```

And to place 98.125 in the fifth element,

```
            times(5) = 98.125
```

The index in these examples is a literal. However, the index can be an integer variable or integer expression.

For example, given the following declarations,

```
real, dimension(10) :: temps
integer :: i=5, j
```

would declare an array with ten elements. To place a value 98.6 in the fifth array element,

```
temps(i) = 98.6
```

To access the fifth element, subtract 3.0 and place the result in the sixth element,

```
temps(i+1) = temps(i) – 3.0
```

To set all elements of the temps array to 0.0, a loop could be used as follows:

```
do j = 1, 10
      temps(i) = 0.0
end do
```

Array elements can be accessed as many times as needed.

13.3 Implied Do-Loop

An implied do-loop is a special form of a loop that can be performed on one line. This can be useful for accessing elements in an array. For example, assuming ***i*** is declared as an integer, the following code,

```
do i = 1, 5
      write(*,*) nums(i)
end do
```

would display each element the 5 element array to the screen.
The same thing can be accomplished with an implied do-loop as follows:

```
write(*,*) (nums(i), i=1,5)
```

Both forms of the loop will display the same results. If necessary, a step can be used. If the step is omitted, as in the example, the step is defaulted to 1.

13.4 Initializing Arrays

An array can be initialized when it is declared. Each element in the array can be initialized to a single value or each element to a different value. The following declaration,

```
real, dimension(10) :: numbers = 1.0
```

will initialize each of the 10 elements in the array numbers to 1.0.

To initialize each element to a different value, each value needs to be specified. For example, the following declaration,

```
real, dimension(5) :: numbers = (/ 1.0, 2.0, 3.0, 4.0 5.0 /)
```

will initialize each of the 5 elements in the array numbers to 1.0, 2.0, 3.0, 4.0, and 5.0 respectively.

The implied do-loop may also be used. For example, in the following declaration,

```
integer, dimension(5) :: numbers = (/ (i, i=1,5) /)
```

will initialize each of the 5 elements in the array numbers to 1, 2, 3, 4, and 5 respectively.

13.5 Example

In this example we will write a Fortran program to read a series of numbers from a file and compute some statistical information including minimum, maximum, sum, average, and standard deviation[8]. The standard deviation is calculated as follows:

$$standard\ deviation \ = \ \sqrt{\frac{\sum_{i=1}^{n} (average - list(i))^2}{n}}$$

As such, the average must be calculated before the standard deviation.

13.5.1 Understand the Problem

The program will display an initial header and get the file name. Specifically, we will need to prompt for the file name, read the file name, and verify that the file is available by attempting to open the file. Then, the program will read the numbers from the file and store them in an array. For this problem, there will be no more than 5000 numbers in the file. After the numbers are in the array, the minimum, maximum, and sum will be found. Next, the average can be computed. Finally, the standard deviation can be calculated in steps, the first of which is computing the inner loop. The numbers should be displayed, ten per line, followed by the results.

13.5.2 Create the Algorithm

After the header is displayed, the program should prompt for the file name, read the file name, and verify that the file is available by attempting to open the file. If the file can not be opened, the program will display an error message and re-prompt. If the user does not enter correct information after three tries, the program should terminate with an appropriate error message. That is, three errors are acceptable, but if a fourth error is made, the program will terminate.

```
! declare variables
!     integer -> i, ncount, errs, opstat, rdstat
!     real -> min, max, sum, stdsum
!     real -> array for
!     character -> filename(20)
! display initial header
! loop
!     prompt for file name
!     read file name
!     attempt to open file
```

[8] For more information, refer to: http://en.wikipedia.org/wiki/Standard_deviation

```
!     if file open successful, exit loop
!     display error message
!     count error
!     if >3 errors, terminate program
! end loop
```

Then, the program will loop to read the numbers from the file and store them in an array. The program will check for any read errors (status variable > 0) and for the end of file (status variable < 0). If a valid number is read, it will be counted and placed in the array.

```
! loop
!     read file
!     if error on read, terminate program
!     if end of file, exit loop
!     increment number counter
!     place number in array
! end loop
```

Next, another loop will be used to find the minimum, maximum, and sum of the numbers. To find the the minimum and maximum values, we will assume that the first element in the array is the minimum and maximum. Then, the program will check each number in the array. If the number from the array is less than the current minimum value, the current minimum value will be updated to the new value. Same for the maximum, if the number from the array is more than the current maximum value, the current maximum value will be updated to the new value.

```
! initialize min, max, and sum
! loop
!     check for new min
!     check for new max
!     update sum
! end loop
```

Once the sum is available, the average can be computed. Finally, a loop will be used to calculate the summation for the standard deviation.

```
! calculate average
! initialize stdsum
! loop
!     calculate average – array item
!     update stdsum
! end loop
```

Once the summation is completed, the standard deviation can be computed and the final results displayed. As per the example specifications, the numbers should be displayed 10 per line. One way to handle this is to display numbers on the same line (with the *advance="no"* clause) and every 10th line display a new line.

```
! calculate standard deviation
! loop to display numbers, 10 per line
! display results
! end program
```

For convenience, the steps are written a program comments.

13.5.3 Develop the Program

Based on the algorithm, the below program could be developed.

```
program standarddeviation

! declare variables
implicit none
integer :: i, ncount, errs, opstat, rdstat
real :: num, min, max, sum, stdsum
real, dimension(5000) :: numbers
character(20) :: filename

! display initial header
      write (*,*) "Standard Deviation Program Example."

! loop
      do

            ! prompt for file name
            write (*,'(a)', advance="no") "Enter File Name:"

            ! read file name
            read (*,*) filename

            ! attempt to open file
            open(42, file=filename, status="old",                &
                        action="read", position="rewind",        &
                        iostat=opstat )

            ! if file open successful, exit loop
            if (opstat==0) exit

            ! display error message
            write (*,'(a)') "Error, can not open file."
            write (*,'(a)') "Please re-enter."

            ! count error
            errs = errs + 1

            ! if >3 errors, terminate program
            if (errs > 3) then
                  write (*,'(a)') "Sorry your having problems."
                  write (*,'(a)') "Program terminated."
                  stop
            end if

      ! end loop
      end do

! loop
      do
            ! read file
            read (42, *, iostat=rdstat) num
            ! if error on read, terminate program
            if (rdstat>0) stop "Error on read."

            ! if end of file, exit loop
            if (rdstat<0) exit

            ! increment number counter
            ncount = ncount + 1

            ! place number in array
            numbers(ncount) = num

      ! end loop
      end do

! initialize min, max, and sum
      min = numbers(1)
      max = numbers(1)
      sum = 0.0

! loop
      do i = 1, ncount

            ! check for new min and new max
            if (numbers(i) < min) min = numbers(i)
            if (numbers(i) > max) max = numbers(i)

            ! update sum
            sum = sum + numbers(i)

      ! end loop
      end do

      ! calculate average
      average = sum / real(ncount)

      ! initialize stdsum
      stdsum = 0.0

! loop
      do i = 1, ncount

            ! calculate (average – array item)^2 and update sum
            stdsum = stdsum + (average - numbers(i))**2

      ! end loop
      end do

! calculate standard deviation
```

```
      std = sqrt ( stdsum / real(ncount) )

! display results
      write (*,'(a)') "-------------------------------"
      write (*,'(a)') "Results:"

      do i = 1, ncount
            write(*,'(2(f8.2,2x))', advance="no") numbers(i)
            if (mod(i,10)==0) write(*,*)
      end do

      write (*,'(a, f8.2)') "Minimum = ", min
      write (*,'(a, f8.2)') "Maximum = ", max
      write (*,'(a, f8.2)') "Sum = ", sum
      write (*,'(a, f8.2)') "Average = ", average
      write (*,'(a, f8.2)') "Standard Deviation = ", std

end program standarddeviation
```

The spacing and indentation is not required, but helps to make the program more easily readable.

13.5.4 Test/Debug the Program

For this problem, the testing would involve executing the program using a file with a set of numbers where the correct results are either known ahead of time or can be calculated by hand in order to verify that the results are accurate.

13.6 Arrays of Strings

An array may also contain characters or strings. The declaration and and access of array elements is the same. However, the string size must be included in the declaration and can not be easily changed once define. For example, to declare an array to hold 100 titles where each title is a maximum of 40 characters,

```
character(40), dimension(100) :: titles
```

Setting an element is the same. For example, to set the first element of the array to the title of this text,

```
titles(1) = Introduction to Programming using Fortran 95
```

Character arrays may be statically or dynamically declared as noted in the previous sections.

13.7 Exercises

Below are some quiz questions and project suggestions based on this chapter.

13.7.1 Quiz Questions

Below are some quiz questions.

1) Explain why an array is considered a direct access structure.

2) Can arrays hold integer values (yes/no)?

3) Can arrays hold real values (yes/no)?

4) Write the declarations for the following:
   a) An integer constant, SIZE1, set to 100
   b) An array with 10 real elements
   c) An array with SIZE1 integer arguments
   d) An array with 10 real elements whose subscript values range from 0 to 9

5) Given the declarations and follow code:

```
integer, dimension(4) :: arr
integer :: k

arr(1) = 10
arr(2) = 15
arr(3) = 20
arr(4) = 25
k = 3
```

   a) What does **`arr(1)`** equal?

   b) What does **`arr(1) + arr(2)`** equal?

   c) What does **`arr(1+2)`** equal?

   d) What does **`arr(k)`** equal?

6) When can an array be allocated (two options)?

7) Given the following statements, what values are in array after execution.

```
integer, dimension(5) :: nums
integer :: i=1

do
      if ( i == 5 ) exit
      if ( mod(i,2) == 0) then
            nums(i) = 0
      else
            nums(i) = i
      end if
      i = i + 1
end do
```

8) What is the **`(nums(i), i=1,5)`** referred to as?

9) What does **`write(*,*) (nums(i), i=1,5)`** display.

13.7.2 Suggested Projects

Below are some suggested projects.

1) Type in the standard deviation program, compile, and execute the program. Test the program on a series of different input values.

2) Write a Fortran program to cube read a series of integer numbers from a file and cube each number. The program should also calculate the real average of the original numbers and the real average of the cubed numbers. Test the program on a series of different input values.

3) Write the program to generate a series of real values between 1.0 and 100.0 and store the numbers in an array. Then, the program should compute the *norm* of a vector (single dimension array). The formula for *norm* is as follows:

$$|norm| = \sqrt{a_1^2 + a_2^2 + a_3^2 + \ldots + a_n^2}$$

Refer to Appendix C for more information regarding generating random numbers. Test the program on a series of different input values.

4) Write a Fortran program to read a series of numbers from a file, store the numbers in an array, and then sort the numbers using the following selection sort algorithm:

```
for  i = len downto 1
      big = arr(1)
      index = 1
      for  j = 1 to i
            if arr(j) > big
                  big = arr(j)
                  index = j
            end_if
      end_for
      arr(index) = arr(i)
      arr(i) = big
end_for
```

You will need to convert the above pseudo-code algorithm into Fortran code. Test the program on a series of different input values.

14 Multidimensional Arrays

A more advanced array is a multidimensional array. A multidimensional array can be thought of as a multiple columns in a spreadsheet. The column name, like ***A***, ***B***, ***C***, etc. are the array columns and the number is like the row.

For example, a two dimension array might look like:

	index	1	2
Array Name	1	<value>	<value>
	2	<value>	<value>
	3	. . .	. . .
		. . .	. . .
		<value>	<value>
	n	<value>	<value>

The specific syntax requires an index or subscript to specify which element of the array to access. The indexing for a two dimension array is:

	index	1	2
Array Name	1	arr(1,1)	arr(1,2)
	2	arr(2,1)	arr(2,2)
	3	arr(3,1)	arr(3,2)
		. . .	. . .
		. . .	. . .
	n	arr(***n***,1)	arr(***n***,2)

By default, the first element is at index=1, the next at index=2, and so forth. This default (where the first number is at index 1) can be changed if needed.

14.1 Array Declaration

Multidimensional array declaration is very similar to single-dimension array declaration. Arrays must be declared before use. The type of the array is defined followed by the size or dimension, which in this case requires a size for each dimension. As before, there are two ways to declare an array; static and dynamic.

14.1.1 Static Declaration

A static declaration means that the size or dimension of the array must be defined initially (before the program is compiled). The size definition can not be altered. The general form of an array declaration is,

```
type, dimension(extent,extent) :: name1, name2, …, nameN
```

where *type* is the data type (integer, real, etc.) of the array. The dimension specifies the the size, and name1, name2, …, nameN are names of one or more arrays being declared.

For example, to declare a two-dimensional array 100 by 100,

```
integer, dimension(100,100) :: nums1
```

will create an array, *nums1*, with space for a total of 1000 integer values.

In this example the extent for each dimension is 100 which means that each of the two dimension's indexes will range form 1 to 100. Each or both extent's can be changed by specifying the extents as:

```
(smaller-integer:larger-integer, smaller-integer:larger-integer)
```

When only one number is specified, the smaller-integer is assumed to be 1. When both numbers, smaller and larger index, are specified the dimension of the array will range between the smaller-integer and the larger-integer. For example, a declaration of:

```
integer, dimension(0:9,0:9) :: ranges
```

will create an array, ranges, with both indexes between 0 and 9 (inclusive). Using index values not within the specified range will result in an error.

14.1.2 Dynamic Declaration

The same as single dimension, a dynamic declaration means that the dimension of the array can be set when the program is executed. Once set, the dimensions can not be altered. When using a dynamic declaration, the array type and name must be defined, which specifies only the name and type of the array, but does not reserve any space for the array. Then, during program execution, the array can be allocated which will create the space for the array. Only after the array has been allocated can it be used.

For example, to declare an array,

```
integer, dimension(:,:), allocatable :: nums2
```

reserving the name *nums2*, but not reserving any space for values.

14.1.3 Dynamic Array Allocation

To allocate the space for the array, the allocate statement must be used. Before an array can be allocated, it must be declared as allocatable.

The general form of the allocate statement is:

```
allocate(<array name>, <dimension>, stat=<status variable>)
```

The status variable must be an integer variable and will be used by the system to place a status code indicating the status (success or failure) of the operation. As before, if the status variable is set to 0, the allocation was successful. If the status variable is set to >0, an error occurred and the allocation was not unsuccessful.

For example, given the declarations,

```
integer, dimension(:,:), allocatable :: nums2
integer :: allstat
```

the following allocate statement allocates space for 1000 numbers in array nums2,

```
allocate(nums2(100,100), stat=allstat)
```

The size, 100 by 100 in this example, can be a parameter or variable, but it must be an integer. The variable *allst* will be set to 0 if the allocation is successful and >0 if the allocation failed.

14.2 Accessing Array Elements

To access elements in an array, the array name and the an index must be specified. The index must include an integer or integer expression for each dimension enclosed in parentheses. The general format is,

```
array-name(<integer expression>, <integer expression>)
```

For example, given the declaration,

```
real, dimension(10,5) :: table1
```

would declare an array, *table1*, with a total of 50 elements. To place a value 121.3 in the first row and first column,

```
table1(1,1) = 121.3
```

And to place 98.125 in the tenth row and fifth column,

```
table1(10,5) = 98.125
```

The index in these examples is a literal. However, the index can be an integer variable or integer expression. For example, given the following declarations,

```
real, dimension(10,10) :: tmptable
integer :: i=2, j=3
```

would declare an array, *tmptable*, with ten elements.

To place a value 98.6 in the second row, fourth column,

```
tmptable(i,j+1) = 98.6
```

To access the same element, subtract 3.0 and place the result back into the same location,

```
tmptable(i,j+1) = tmptable(i,j+1) – 3.0
```

To set all elements of the *tmptable* array to 0.0, a nest loop could be used as follows:

```
do i = 1, 10
     do j = 1, 10
          tmptable(i,j) = 0.0
     end do
end do
```

In addition, the entire array can be set to 0 in the following statement,

```
tmptable = 0.0
```

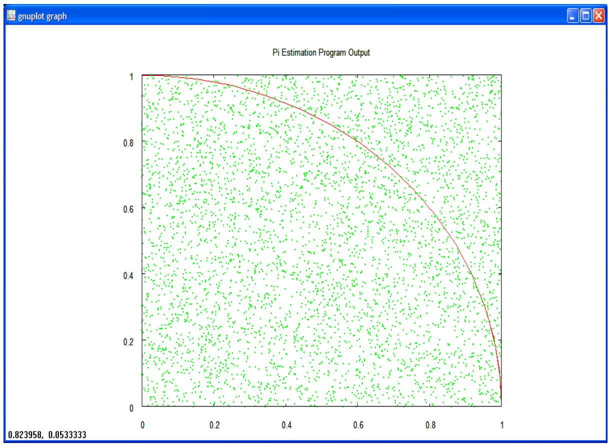
Array elements can be accessed as many times as needed.

14.3 Example

In this example we will write a Fortran program that will request a count, generate count (***x***,***y***) random points, and perform a Monte Carlo ***π*** estimation based on those points. All ***x*** and ***y*** values are between 0 and 1. The main routine will get the count and the use a subroutine to generate the random (***x***,***y***) points and a function, to perform the Monte Carlo ***π*** estimation. For this example, the count should be between 100 and 1,000,000.

14.3.1 Understand the Problem

Based on the problem definition, we will use a main routine that will get and check the count value. If the count is not between 100 and 1,000,000, the routine will re-prompt until the correct input is provided. Once a valid count value is obtained, then the main will allocate the array and call the two subroutines. The first subroutine will generate the random (***x***,***y***) points and store them in an array. The second subroutine will perform the Monte Carlo ***π*** estimation.



Monte Carlo methods are a class of computational algorithms that rely on repeated random sampling to compute their results. Suppose a square is centered on the origin of a Cartesian plane, and the square has sides of length 2. If we inscribe a circle in the square, it will have a diameter of length 2 and a radius of length 1. If we plot points within the upper right quadrant, the ratio between the points that land within the inscribed circle and the total points will be an estimation of ***π***.

$$est\ \pi \ = \ 4 \left(\frac{\text{samples inside circle}}{\text{total samples}} \right)$$

As more samples are taken, the estimated value of ***π*** should approach the actual value of ***π***. The Pythagorean theorem can be used to determine the distance of the point from the origin. If this distance is less than the radius of the circle, then the point must be in the circle. Thus, if the square root of ($\boldsymbol{x}^2$+$\boldsymbol{y}^2$) < 1.0, the random point is within the circle.

Finally, the figure we are discussing, a square centered on the origin with an inscribed circle is symmetric with respect to the quadrants of its Cartesian plane. This works well with the default random number generations of values between 0 and 1.

14.3.2 Create the Algorithm

The main routine will display an initial header, get and check the count value, and allocate the array. The program will need to ensure that the array is correctly allocated before proceeding. Then program can generate the (***x***,***y***) points. Based on the problem definition, each point should be between 0.0 and 1.0 which is provided by default by the Fortran random number generator. Next, the program can perform the Monte Carlo ***pi*** estimation. This will require the already populated (***x***,***y***) points array and the count of points. Each point will be examined to determine the number of points that lie within the inscribed circle. The Pythagorean theorem allows us to determine the distance of the point from the origin (0.0,0.0). Thus, for each point, we will calculate the $\sqrt{(x2+y2)}$ and if the distance is less than the circle radius of 1.0, it will be counted as inside the circle.

Then, the estimated value of $\boldsymbol{\pi}$ can be calculated based on the formula:

$$est\ \pi \ = \ 4\left(\frac{\textbf{samples inside circle}}{\textbf{total samples}}\right)$$

When completed, the program will display the final results. The basic algorithm is as follows:

```
! declare variables
! display initial header
! prompt for and obtain count value
!     loop
!           prompt for count value
!           read count value
!           if count is correct, exit loop
!           display error message
!      end loop
! allocate two dimension array
! generate points
!     loop count times
!           generate x and y values
!           place (x,y) values in array at appropriate index
!     end loop
! set count of samples inside circle = 0
!     loop count times
!           if [ sqrt $(x(i)^2+y(i)^2)$ < 1.0 ]
!                 increment count of samples inside circle
!     end loop
! display results
```

For convenience, the steps are written a program comments.

14.3.3 Develop the Program

Based on the algorithm, the below program could be developed.

```
program piestimation

! declare variables
implicit none
integer :: count, alstat, i, incount
real :: x, y, pi_est, pt
real, allocatable, dimension(:,:) :: points

! display initial header
      write (*,'(/a/)') "Program Example – PI estimation."

! prompt for and obtain count value
      do
            ! prompt for count value
            write (*,'(a)', advance="no")                       &
                        "Enter Count (100 – 1,000,000): "

            ! read count value
            read (*,*) count

            ! if count is correct, exit loop
            if ( count >= 100 and count <= 1000000 ) exit

            ! display error message
            write (*,'(a,a,/a)') "Error, count must be ",         &
                              "between 100 and 1,000,000.",      &
                              "Please re-enter."
       end do

! allocate two dimension array
      allocate (points(count,2), stat=alstat)
      if (alstat <> 0 ) then
            write (*,'(a,/a)') "Error, unable to allocate"       &
                        " memory.", "Program terminated."
            stop
      end if

! generate_points
      call random_seed()

      ! loop count times
      do i = 1, cnt

            ! generate x and y values
            call random_number(x)
            call random_number(y)

            ! place (x,y) values in array
            pts(i,1) = x
            pts(i,2) = y
      end do

! perform monte carlo estimation
      ! set count of samples inside circle = 0
      incount = 0

      ! loop count times
      do i = 1, cnt

      ! if [ sqrt (x(i)^2+y(i)^2) < 1.0 ]
      !     increment count of samples inside circle

            pt = pts(i,1)**2 + pts(i,2)**2
            if (sqrt(pt) < 1.0) incount = incount + 1

      end do

      pi_est = 4.0 * real(incount) / real(cnt)


! display results
      write (*,'(a, f8.2)') "Count of points: ", count
      write (*,'(a, f8.2)') "Estimated PI value: ", pi_est

end program piestimation
```

The spacing and indentation is not required, but helps to make the program more easily readable.

14.3.4 Test/Debug the Program

For this problem, the testing would involve executing the program using a series of different count values and ensure that the **π** estimate is reasonable and improves with higher count values.

14.4 Exercises

Below are some quiz questions and project suggestions based on this chapter.

14.4.1 Quiz Questions

Below are some quiz questions.

1) Can multidimensional arrays hold both integer and real values (yes/no)?

2) What is the order of the indexes:
    1. (row, column)
    2. (column, row)
    3. (row, row)
    4. (column, column)
    5. user-selectable

3) Given the following code:

```
real, dimension(5,3) :: mdarr
integer :: i, j

do i = 1, 5
      do j = 1, 3
            mdarr(i,j) = real(i+j)
      end do
end do
```

   a) How many values, total, can be stored in the **`mdarr`** array?
   b) Show the contents of every cell in the **`mdarr`**. (5 pts)
   c) What does **`mdarr(2,1)`** contain?
   d) What does **`mdarr(1,3)`** contain?
   e) What does **`mdarr(4,3)`** contain?

4) How can an unsuccessful multidimensional dynamic allocation be detected?

14.4.2 Suggested Projects

Below are some suggested projects.

1) Type in the **π** estimation program compile, and execute the program. Test the program on a series of different point count values. Demonstrate that larger point values provide a better estimation.

2) Update the **π** estimation program to ensure that a valid count values is obtained within three tries. If there are more than three errors, the program should display an error message and terminate.

3) Update the **π** estimation program to display the estimated **π** value 10 times. In order to perform this, the count value can be divided by 10 and the current estimated **π** value displayed.

4) Write a program to statically declare a 100x100 two dimensional array of real values. The program should populate the array with random numbers between 0 (inclusive) and 1 (exclusive). Refer to Appendix C for information regarding generating random numbers. The program should scan the array to find and display the maximum value and the location of that value (ie., the row and column where the value was found).

5) Update the find maximum program (from the previous question) to declare the array dynamically and allow the user to enter a the row and column dimension's and ensure that each is between 10 and 1000. Once entered, the program should allocate the array and find and display the maximum and minimum values and their locations (row and column).

6) Write a Fortran program to construct an odd-order Magic Square[9]. The algorithm for constructing an NxN ***odd*** ordered Magic Square is as follows:

   - First, place a **1** in the middle of the top row.
   - After placing an integer, ***k***, move up one row and one column to the right to place the next integer, ***k+1***, unless the following occurs:
     - If a move takes you above the top row in the ***j***th column, move to the bottom of the ***j***th column and place the integer there.
     - If a move takes you outside to the right of the square in the ***i***th row, place the integer in the ***i***th row at the left side.
     - If a move takes you to an already filled square or if you move out of the square at the upper right hand corner, place ***k+1*** immediately below ***k***.

   Test the program and compare the results to the Wikipedia example.

[9] For more information, refer to: http://en.wikipedia.org/wiki/Magic_square

15 Subprograms

Until now, all of the programs have essentially been a single, fairly small programs. However, as we scale up into larger programs, this methodology will become more difficult. When developing larger programs, it becomes necessary to break the larger program up into multiple, smaller more manageable pieces. Then, during program development, it is possible to focus on each subsection or piece individually and then combine the results into a final complete program. And, for very large projects, multiple people may work on different parts of the program simultaneously.

Some of the key advantages of developing a program using functions and/or subroutines include:

- Structured development of programs
- Reuse of subprograms
- Isolation of subprograms

Fortran subprograms are the mechanism to break a large program into multiple smaller parts. This allows for a more comprehensive program design.

15.1 Subprogram Types

There are two types of Fortran subprograms: *functions,* and *subroutines*, each of which is explained in the following sections.

15.2 Program Layout

The functions and subroutines can be defined as either internal or external. Internal functions and subroutines are be defined within the program statement (i.e., before the “end program <name>” statement).

The basic layout for both internal and external subprograms is as follows:

```
program <name>

<declarations>
<program statements>

contains

<internal functions or subroutines>

end program <name>

<external functions or subroutines>
```

Where a combination of both or either internal or external routines is allowed.

15.2.1 Internal Routines

Internal routines require the keyword "contains" to separate the from the program code. Primarily, internal routines will be used in this text for simplicity. There is no limit to the number of internal routines. However, if too many routines are included the file will become large and large files can be difficult to work with.

15.2.2 External Routines

External functions are defined outside the program statement (i.e., after the "end program <name>" statement) or in another file. For larger programs external routines would be used extensively. However, additional set-up statements, including an *external declaration* and an *interface block*, are required. The definition and use of external routines is not addressed in this chapter.

15.3 Arguments

When writing and using Fortran subprograms, it is typically necessary to provide information to and/or obtain results from the functions or subroutines. This information, in the form of variables, is referred to as an argument or arguments. The argument or arguments in the calling routine is referred to as *actual arguments* and the argument or arguments in the function or subroutine are referred to as *formal arguments*. The formal arguments take on the values that are passed from the calling routine.

The only way to transfer values in to or out of a function or subroutine is through the arguments. All other variables are independent and isolated.

15.3.1 Argument Intent

Subprograms often return values by altering or update the some of the arguments. When passing a variable, the information (value or values) can be passed into the function or subroutine. This is referred to as "intent(in)". If the variable is to be set by the subroutine, that is referred to as "intent(out)". If the variable contains a value or values (i.e., an array) that are to be passed into the subroutine and altered in some way by the subroutine and returned back to the calling routine, that is referred to as "intent(inout)".

15.4 Variable Scope

The variable *scope* refers to where a given variable can be accessed. Scope rules tell us if an entity (i.e., variable, parameter, and/or function) is visible or accessible at certain places. Places where an entity can be accessed or visible is referred as the scope of that entity. The variables defined in a subprogram is generally not visible to the calling routine. Thus a variable ***x*** in the calling routine is different than a variable ***x*** in the subprogram.

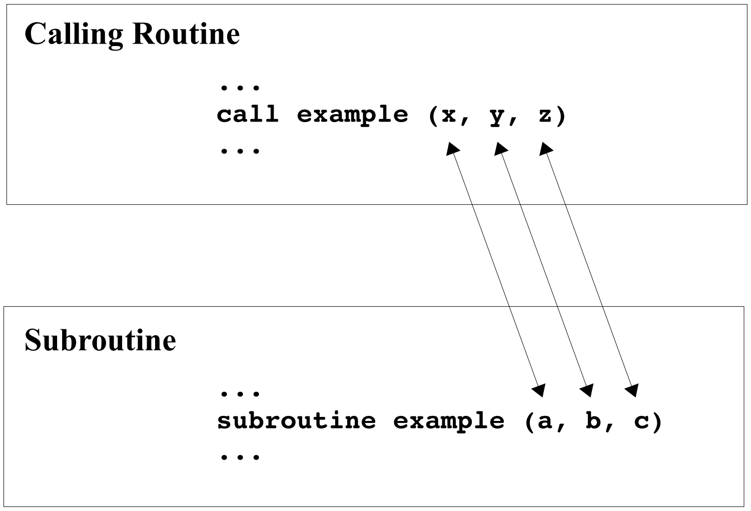
15.5 Using Functions and Subroutines

Before a function or subroutine can be used, it must be defined or written. Once defined, the subroutine or function can be used or *called*. A function is called by using its name as we have done with the intrinsic functions. When a program uses a subroutine it is called with a *call statement*.

15.5.1 *Argument Passing*

When using functions and/or subroutines, information (values, variables, etc.) are typically passed to or from the routines. Argument association is a way of passing values from actual arguments to formal arguments. If an actual argument is an expression, it is evaluated and passed to the corresponding formal argument. If an actual argument is a variable or constant, its value is passed to the corresponding formal argument. There must be a one-to-one correspondence between the actual argument (calling routine) and the formal argument (subroutine/function).

The arguments in the call are matched up to the arguments in the subroutine by ***position***. Each of the arguments is matched by position. The names of the variables do not need to match, however the data types must match.



```
...
call example (x, y, z)
...
```

```
...
subroutine example (a, b, c)
...
```

Other variables in either the calling routine or the subroutine are isolated from each other. As such, the same variable name can be re-used in both the calling routine and the subroutine (and refer to different values).

15.6 Functions

A function is a special type of Fortran subprogram that is expected to return a single result or answer. A function will typically accept some kind of input information and based on that information, return a result. The two types of Fortran functions are described in the following sections.

15.6.1 *Intrinsic Functions*

A described previously, an *intrinsic function* is a built-in function that is already available. Some of the intrinsic functions already described include *sin()*, *cos()*, *tan()*, *real()*, *int()*, and *nint()*. A more comprehensive list is contained in Appendix D.

15.6.2 *User-Defined Functions*

A user-defined function are functions that a written by the user for specific or specialized requirements.

The general form of a user-defined function is a follows:

```
<type> function <name> ( <arguments> )
<declarations>

      <body of function>

      <name> = expression
      return
end function <name>
```

The <type> is one of the Fortran data types; real, integer, logical, character, or complex. It is possible to place the type declaration on a separate line from the functions statement.

The information, in the form of arguments, is passed from the calling routine to the function. Each of the passed arguments must be declared and the declaration must include the type and the intent. The arguments in the calling routine and the function must match and are matched up by position.

An example function to convert a Fahrenheit temperature to Celsius temperature would be as follows:

```
real function fahr_to_celsius(ftemp)
real, intent(in) :: ftemp

     fahr_to_celsius = (ftemp – 32.0) / 1.8

     return
end function fahr_to_celsius
end program quiz
```

Which, given a Fahrenheit temperature, will return the Celsius temperature. The single input argument, *ftemp*, is declared to be a real value and “intent(in)”, which means that the value is expected to be coming into the function and can not be changed. The final value is returned to the calling routine by assigning a value to the function name, *fahr_to_celsius*, in this example.

15.6.2.1 Side Effects

A *side-effect* is when a function changes one or more of its input arguments. Since the arguments can be declared as “intent(out)” or “intent(inout)”, the function could change the arguments. In general, this is consider poor practice and should be avoided. None of the examples in this text will include or utilize side-effects.

15.7 Subroutines

A subroutine is a Fortran subprogram that can accept some kind of input information and based on that information, return a result or series of results.

The general form of a subroutine is a follows:

```
subroutine <name> ( <arguments> )
<declarations>

      <body of subroutine>

      return
end function <name>
```

The information, in the form of arguments, is passed from the calling routine to the function. Each of the passed arguments must be declared and the declaration must include the type and the intent. The arguments in the calling routine and the subroutine must match and are matched up by position.

For example, given the following simple program to find the sum and average of three numbers.

```
program subexample

implicit none
real :: x1=4.0, y1=5.0, z1=6.0, sum1, ave1
real :: x2=4.0, y2=5.0, z2=6.0, sum2, ave2

    call smave(x1, y1, z1, sum1, ave1)
    write(*,'(a,f5.1,3x,a,f5.1)') "Sum=", sum1, "Average=", ave1

    call smave(x2, y2, z2, sum2, ave2)
    write(*,'(a,f5.1,3x,a,f5.1)') "Sum=", sum2, "Average=", ave2

contains

subroutine smave (a, b, c, sm, av)
real, intent(in) :: a, b, c
real, intent(out) :: sm, av

      sm = a + b + c
      av = sm / 3.0

      return
end function smave

end program subexample
```

The arguments in the first call (*x1*, *y1*, *z1*, *sum1*, and *ave1*) are matched up to the arguments in the subroutine (*a*, *b*, *c*, *sm*, and *av*) by ***position***. That is, the *x1* from the call is matched with the *a* in the subroutine. The arguments in the second call (*x2*, *y2*, *z2*, *sum2*, and *ave2*) are again matched up to the arguments in the subroutine (*a*, *b*, *c*, *sm*, and *av*) by ***position***. While the names of the variables do not need to match, the data types must match. Variables declared in a function or subroutine are not the same as variables in the calling routine. This is true, even if they are the same name!

15.8 Example

In this example we will write a Fortran program to simulate the dice game of Twenty-Six[10] which is single player betting game with 10 dice. The main program will determine how many games to play. A subroutine will be used to play the Twenty-Six game. The subroutine will be called as many times as requested. The main will track the count of games won and lost and display the win/loss record and the win percentage.

The subroutine, ***twenty_six()***, will play the game dice game Twenty-Six. To play the game, the player rolls the dice (1 to 6) and this initial roll is used as the "point" number. Then the player throws the ten dice 13 times. The score is the number of times that the point number is thrown. A random number between 1 and 6 will be used for each dice roll.

The routine will determine the payout based on the point count using the following table:

Point Count	Payout
10 or less	10
13	5
26	4
27	5
28	6
29	8
30	10
Other	0

The subroutine should display the dice (all 10 dice for each of 13 rolls), point count, game result, payout. For example, if the point was 6, the subroutine might display the following:

```
Point:  6
   Roll:  1  Dice:    4  6  5  3  3  1  1  3  3  2
   Roll:  2  Dice:    1  6  3  3  4  1  4  4  2  6
   Roll:  3  Dice:    3  2  6  4  5  3  2  1  5  4
   Roll:  4  Dice:    5  6  4  1  4  6  6  2  4  4
   Roll:  5  Dice:    4  6  6  4  5  3  6  1  5  5
   Roll:  6  Dice:    3  1  4  5  6  5  3  3  3  4
   Roll:  7  Dice:    6  6  5  6  1  5  5  6  5  5
   Roll:  8  Dice:    4  1  3  4  1  4  4  6  2  5
   Roll:  9  Dice:    4  4  2  1  1  4  3  1  5  4
   Roll: 10  Dice:    5  6  1  2  4  1  1  2  1  1
   Roll: 11  Dice:    2  3  2  4  1  3  3  6  5  1
   Roll: 12  Dice:    1  1  6  5  4  5  1  6  6  5
   Roll: 13  Dice:    6  4  4  5  3  3  5  3  3  5
Point Count: 22
Game Result: LOSS    Payout =  0
```

For this example, the main will track the games won and lost.

[10] For more information, see: http://homepage.ntlworld.com/dice-play/Games/TwentySix.htm

15.8.1 Understand the Problem

The program will display an initial header and get the number of games to play. Specifically, we will need to prompt for the count of games and and verify that the count is between 2 and 1,000,000 (arbitrarily chosen). Then, the program will call the ***twenty_six()*** subroutine count times. After each game, the main will update the count of games won. The main will also track the payout and bank value status, which is initialized to 100 (chosen arbitrarily) and updated after each game is played.

An example main is provided as follows:

```
program dicegame

!------------------------------------------------------------
! Fortran program to simulate a dice game of Twenty-Six
!     The main program:
!           displays appropriate headers
!           obtains and checks number of games to play
!           loops to play 'count' number of games times

implicit none
integer, parameter :: initial_bank=100
integer :: num_games, games_won=0, games_lost=0
integer :: i, payout, bank
integer, dimension(13,10) :: dice
real :: win_pct

      write (*, '(/a/a/)')                                        &
            "--------------------------------",                   &
            "Dice Game ""Twenty-Six"" Simulator."

      do
            write (*, '(2x, a )', advance = "no")                 &
                  "Enter number games to simulate: "
            read (*,*) num_games
            if (num_games >= 1 .and. num_games <= 1000000) exit
            write (*, '(2x, a)') "Error, number of ",             &
                        "games must be between 1 and 1000000."
            write (*, '(2x, a)') "Please re-enter."
      end do

      bank = initial_bank
      call random_seed()

      do i = 1, num_games

            bank = bank - 1

            call twenty_six (payout)

            if (payout > 0) then
                  games_won = games_won + 1
            else
                  games_lost = games_lost + 1
            end if
            bank = bank + payout

      end do

      win_pct = ( real(games_won) / real(num_games) ) * 100.00

      write (*,'(/a,/a/,3(2x,a,i9/),2(2x,a,i8/),2x,a,f4.1,a)')       &
            "------------------------------------------------"       &
            "Games Statistics:",                                     &
            "Game Count:   ", num_games,                             &
      "Games Won:    ", games_won,                                   &
            "Games Lost:   ", games_lost,                            &
            "Initial Bank:  ", initial_bank,                         &
            "Final Bank:    ", bank,                                 &
            "Win Percentage:   ", win_pct, "%"

contains

! **********************************************************
!     subroutine(s) goes here...
! **********************************************************

end program dicegame
```

Refer to Appendix C for additional information regarding the random number generation and initialization of the built-in random number generator.

15.8.2 Create the Algorithm

Since the main is provided, the algorithm will focus on the twenty-six game. Since the built-in random number generator provides random numbers between 0.0 and 1.0, they will need to be scaled and converted to an integer between 1 and 6 (for a dice). The initial point value must first be established followed by a loop to throw the ten dice 13 times in accordance with the game rules. The results will be stored in a two-dimensional array. While not strictly required, it does provide an additional example of how to use a two-dimensional array. Finally, the payout will be determined based on the game rules.

```
! Randomly select a number from 1 to 6 as the "point" number
! Throw ten dice 13 times
!     results go into dice(13,10) array
! Score is the number of times that the point number
!     is thrown
! determine payout
```

For convenience, the steps are written a program comments.

15.8.3 Develop the Program

Based on the algorithm, the below program could be developed.

```
! **********************************************************
! Subroutine to simulate twenty-six game.
!     Randomly select a number from 1 to 6 as the “point” number
!     Throw ten dice 13 times
!           results go into dice(13,10) array
!     Score is the number of times that the point number is thrown

subroutine twenty_six (payout)

implicit none
integer, dimension(13,10) :: dice
integer, intent(out) :: payout
integer :: point, pnt_cnt
real :: x
integer :: i, j

!     determine point
      call random_number(x)
      point = int(x*6.0) + 1

!     roll dice
      pnt_cnt = 0

      do i = 1, 13

            do j = 1, 10
                  call random_number(x)
                  dice(i,j) = int(x*6.0) + 1
                  if (dice(i,j) == point) pnt_cnt = pnt_cnt + 1
            end do

            ! determine payout
            select case (pnt_cnt)
                  case (6, 10)
                        payout = 10
                  case (13,27)
                        payout = 5
                  case (26)
                        payout = 4
                  case (28)
                        payout = 6
                  case (29)
                        payout = 8
                  case (30:36)
                        payout = 10
                  case default
                        payout = 0
            end select

      end do

      write (*,'(/,5x,a,/,5x,a,i2,/,5x,a,i2)')                 &
                 "-------------------------------------",      &
                 "Point: ", point

      do i = 1, 13
            write (*,'(8x, a, i2, 2x, a, 10(2x, i1),/)',       &
                  advance="no") "Roll: ", i, "Dice: ",             &
                              (dice(i,j), j=1,10)
      end do

      write (*,'(/,5x,a,i2)') "Point Count: ", pnt_cnt

      if (payout > 0) then
            write (*,'(5x,a,i2)')                                  &
                  "Game Result: WIN     Payout = ", payout
      else
            write (*,'(5x,a,i2)')                                  &
                  "Game Result: LOSS    Payout = ", payout
      end if

      write (*,'(5x,a,i6)') "Bank:", bank

      return
end subroutine twenty_six
```

The spacing and indentation is not required, but helps to make the program more easily readable.

15.8.4 Test/Debug the Program

For this problem, the testing would involve executing the program using a file with a set of numbers where the correct results are either known ahead of time or can be calculated by hand in order to verify that the results are accurate.

15.9 Exercises

Below are some quiz questions and project suggestions based on this chapter.

15.9.1 Quiz Questions

Below are some quiz questions.

1) What are the two types of Fortran subprograms?

2) How many values does a user-defined function typically return?

15.9.2 Suggested Projects

Below are some suggested projects.

1) Type in the dice game program example, compile, and execute the program. Test the program by playing it for a series of rounds. Ensure the scoring is correct.

2) Write a main program and an integer Fortran function, ***gSeries()***, to compute the following geometric series:

$$g = \sum_{n=0}^{n-1} x^n = 1+x+x^2+x^3+\cdots+x^{(n-1)}$$

The arguments for the call, in order, are as follows; n (integer value). The function should return an integer result. The main should call the function with several different values.

3) Write a main program and a real function, ***harmonicMean()***, to compute the harmonic mean of a series of real numbers. The real numbers are pass to the function in an array along with the count.

$$harmonic\,mean = \frac{N}{\left(\frac{1}{x_1}+\frac{1}{x_2}+...+\frac{1}{x_N}\right)}$$

The arguments for the call, in order, are as follows; array of numbers (*count* real values), count (integer). The function should return an real result. The main should call the function with several different values.

4) Write a main program and a subroutine, ***CircleStats()***, that, given an array containing a series of circle diameter's (real values), will compute the area of each circle in a series of circles and store them into a different array (real values). The subroutine should also compute the real average of the circle areas. The arguments for the call, in order, are as follows; circle diameter's array (*count* real values), circle areas array (*count* real values), count (integer), areas average (real). The main program should declare the array and initialize the array with a series of values for circle areas. The program results should be verified with a calculator.

5) Write a main program and a subroutine, ***ReadCoord()***, to read an (***x,y,z***) coordinate from the user. The subroutine must prompt for and read (***x,y,z***) and ensure that the ***x***, ***y***, and ***z*** values are between 0 and 100 (inclusive). The values may be prompted for and read together, but prompt should leave the cursor on the same line. The subroutine should re-prompt for all three if the input data is not correct. If the user provides valid data, the (***x,y,z***) values should be returned with a logical for valid data set to *true*. If the user does not provide valid data entry after **three** tries, the subroutine should display an error message and a set the logical for valid data to *false*. The arguments for the call, in order, are as follows; ***x*** value (integer), ***y*** value (integer), ***z*** value (integer), and valid data flag (logical value). The main program should call the subroutine three times and display the results for each call.

6) Write a main program and a subroutine, ***Stats()***, that, given an array containing a series of numbers (real values), will find and display the following real values; minimum, median, maximum, sum, and average. The display must use a formatted write(). The real values will not exceed 100.0 and should display three digits decimal values (i.e., ***nnn.xxx***). The arguments for the call, in order, are as follows; array of numbers (*count* real values), count (integer). The main program should populate the array with random numbers and call the subroutine.

16 Derived Data Types

A derived data type is a user-defined combination of the intrinsic data types. The derived data types are a convenient way to combine or group variables about a particular item.

For example, a 'student' might include a name, identification number, final score, and grade. Each of these pieces of information can be represented with individual variables (as outlined in previous section) as follows:

```
character(50) :: name
integer :: id
real :: score
character(2) :: grade
```

However, for multiple students, multiple sets of variables would be required. This can become cumbersome and confusing.

By using a derived data type, these separate pieces of information can be more easily grouped together. The details on defining, declaring and using derived data types are provided in the following sections.

16.1 Definition

Before a derived data type can be used, it must be defined. The definition will establish the pieces of information will be grouped together. Each piece of information included in the definition is referred to as a component.

```
type type_name
      <component definitions>
end type type_name
```

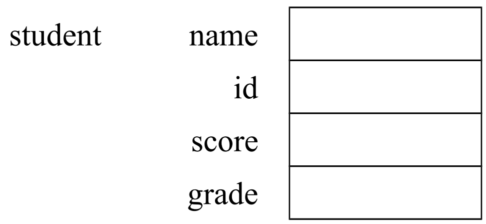
For example, to declare the student type described previously, the following declaration would be appropriate:

```
type student
      character(50) :: name
      integer :: id
      real :: score
      character(1) :: grade
end type student
```

The indentation is not required, but does make the definition easier to read. Each of the fields (name, id, score, grade) are called components. These components together make up the information for a 'student'.

The type definition is required only once at the beginning of the program. Once defined, the type definition can not be changed. More specifically, additional components can not be added unless the definition is updated and program is recompiled.

This definition will establish a template as follows:



Once defined, the template can be used to declare variables. Each variable declared with this definition will be created based on the definition which includes the these four components.

16.2 Declaration

Once a derived data type is defined, variables using that definition can be declared. The general format for a declaration is as follows:

```
type (<type_name>) :: <variable_name(s)>
```

For example, to declare two students, the following declaration could be used:

```
type (student) :: student1, student2
```

This declaration will declare two variables, *student1* and *student2*, each with the set of components defined in the type definition. The definition can be thought of as the cookie cutter and the declaration is the cookie. Only after a variable has been declared, can values be set for that variable.

16.3 Accessing Components

Once some variables using the derived data type have been declared, the individual components can be accessed. First the variable name is specified, followed by a "%" (percent sign), and then the component name. The general format is:

```
<variable_name>%<component_name>
```

For example, to set all components for the student student1, the following

```
student1%name = "Joesph"
student1%id = 1234
student1%score = 99.99
student1%grade = "A"
```

Each component for *student1* is set individually. Not every component must be set. Of course, as with other variables, an component that has not been set can not be used.

This previous declaration and these assignments will establish a variable as follows:

student	name	**Joesph**
	id	**1234**
	score	**99.99**
	grade	**A**

It is possible to assign all components to another variable of the same derived data type. For example, to set *student2* to the same as *student1*, an assignment is used as follows:

```
student2 = student1
```

This will copy all components from the variable *student1* into the variable *student2* (since both *student1* and *student2* are of the same derived data type).

16.4 Example One

In this example, we will write a simple program to read two times from the user, time one and time two, and calculate the sum of the two times. For this example, the time will consist of hour, minutes, seconds in 24-hour format. For this exercise, the hours may exceed 23 when the times are summed. The program should declare the appropriate variables using a derived data type, use a subroutine to read a time (which should be called twice), and another subroutine to calculate the sum of the times. The subroutine to read the times must perform appropriate error checking. The main should display both the times and the final time sum.

16.4.1 Understand the Problem

The main is expected to define the appropriate derived data type for time, declare some variables of that type and call the subroutines. The first subroutine will read a time from the user which will consist of hour, minutes, and seconds in 24-hour format. This subroutine will be called twice. The second subroutine will add the times together and provide a result.

The first subroutine to read a time from the user is expected to perform error checking on the data entered by the user. Specifically, this requires that hours range from 0 to 23, minutes range from 0 to 59, and seconds range from 0 to 59. Values outside these ranges, 60 seconds for example, are not valid. For this simple example, we will re-prompt for incorrect data entry (until correct data is provided).

The second subroutine will add the two times and must ensure that the correct ranges for seconds and minutes are maintained. When adding the two times, it is possible to add the seconds, minutes, and hours. However, if the sum of the two seconds values exceeds 60, the seconds must be adjusted and the minutes must be updated accordingly (add one extra minute). This applies to the minutes as well. However, when added in this exercise, the final time sum hours may exceed 23 hours.

For example, given time one as 14 hours, 47 minutes and 22 seconds (i.e., 14:47:22) and time two as 18 hours, 22 minutes, and 50 seconds, (i.e., 18:22:50), the total time would be 33 hours, 10 minutes and 12 seconds (i.e., 33:10:12).

16.4.2 Create the Algorithm

For this example there are three parts; the main, the read time subroutine, and the time summation subroutine. The basic steps for the main include:

```
! define derived data type for time
!     must include → hours, minutes, seconds
! declare variables, including → time1, time2, and timesum
! display initial header
! call subroutine to read time1
! call subroutine to read time2
! call subroutine to add times
! display results
```

The basic steps for the read time subroutine include:

```
! subroutine header and appropriate declarations
! loop
!     prompt for time
!     read time (hours, minutes, seconds)
!     check time entered
!     → if [ hours(0-23), minutes(0-59), seconds (0-59) ] exit
!     display error message
! end loop
```

The basic steps for the time summation subroutine include:

```
! subroutine header and appropriate declarations
! add the seconds
! add the minutes
! add the hours
! if seconds > 59, then
!     subtract 60 from seconds
!     add 1 to minutes
! if minutes > 59, then
!     subtract 60 from minutes
!     add 1 to hours
```

For convenience, the steps are written a program comments.

16.4.3 Develop the Program

Based on the algorithm, the below program could be developed.

```
program timeSummation

! define derived data type for time (hours, minutes, seconds)
implicit none
type time
      integer :: hours, minutes, seconds
end type
```

```
! declare variables
!     includes → time1, time2, and timesum
type(time) :: time1, time2, timesum

! display initial header
      write (*,'(/,a,/)') "Time Summation Example Program."

! call subroutine to read each time
      call  readtime(time1)
      call  readtime(time2)

! call subroutine to add times
      call  addtimes(time1, time2, timesum)

! display results
      write (*,'(/,a,i2.2,a1,i2.2,a1,i2.2)') "Time One: ",        &
            time1%hours, ":", time1%minutes, ":", time1%seconds
      write (*,'(a,i2.2,a1,i2.2,a1,i2.2)') "Time Two: ",          &
            time2%hours, ":", time2%minutes, ":", time2%seconds
      write (*,'(a,i2.2,a1,i2.2,a1,i2.2,/)') "Time Sum: ",        &
            timesum%hours, ":", timesum%minutes, ":",             &
                  timesum%seconds

contains

! *******************************************************
!  Subroutine to prompt for, read, and check
!     a time (hours:minutes:seconds) in 24-hour format.

subroutine readtime ( timeval )
type(time), intent(out) :: timeval

      do
!     prompt for time
            write (*,'(a)',advance="no") "Enter time (hh:mm:ss): "

!     read time (hours, minutes, seconds)
            read (*,*) timeval%hours, timeval%minutes, timeval%seconds

!     check time entered
            if ( timeval%hours >= 0 .and. timeval%hours <= 23.and.    &
                  timeval%minutes >= 0 .and. timeval%minutes <= 59    &
                  .and. timeval%seconds >= 0 .and.                    &
                        timeval%seconds <= 59 ) exit

!     display error message
            write (*,'(a,/,a)') "Error, invalid time entered.",       &
                  "Please re-enter time."

      end do

      return
end subroutine readtime
```

```
! *******************************************************
!  Subroutine to add two times.
!     Ensures seconds and minutes are within range (0-59)
!     Hours may exceed 23

! subroutine header and appropriate declarations
subroutine addtimes ( tm1, tm2, tmsum )
type(time), intent(in) :: tm1, tm2
type(time), intent(out) :: tmsum

! add the seconds, minutes, hours
      tmsum%seconds = tm1%seconds + tm2%seconds
      tmsum%minutes = tm1%minutes + tm2%minutes
      tmsum%hours = tm1%hours + tm2%hours

! if minutes > 59, subtract 60 from seconds and add 1 to minutes
      if (tmsum%seconds > 59) then
            tmsum%seconds = tmsum%seconds - 60
            tmsum%minutes = tmsum%minutes + 1
      end if

! if minutes > 59, subtract 60 from minutes and add 1 to hours
      if (tmsum%seconds > 59) then
            tmsum%minutes = tmsum%minutes - 60
            tmsum%hours = tmsum%hours + 1
      end if

      return
end subroutine addtimes

end program timeSummation
```

If the program does not work at first, the comments can aid in determining the problem.

16.4.4 Test/Debug the Program

For this problem, the testing would involve executing the and entering a series of various time values to ensure that the results are correct. If the program does not work initially, the functionality of each subroutine should be checked. The times read from the user can be displayed to the screen to ensure they are correct. Once the times are correct, the add times subroutine can be checked. Each of the time sums can be displayed to help determine where the error might be.

16.5 Arrays of Derived Data

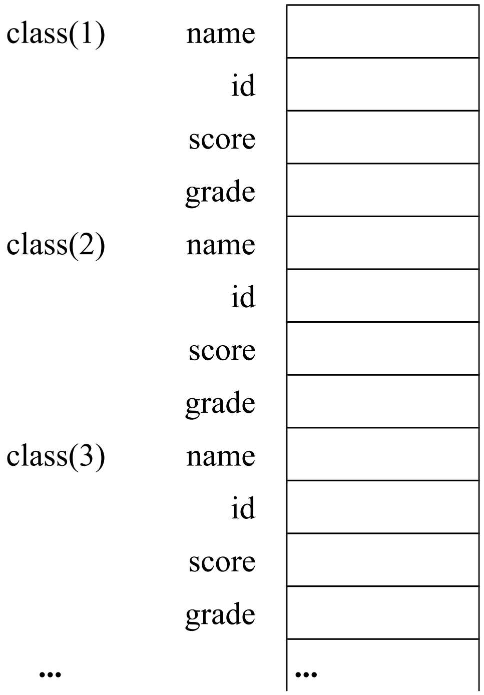
In addition to declaring single variables based on the derived data type definition, it is possible to declare an array based the derived data type definition.

For example, to declare an array named class to hold 30 elements of type student, the following declaration can used used.

```
type(student), dimension(30) :: class
```

Each element of the array class will be of the type student and include each of the defined components (name, id, score, grade in this example).

For example, the layout would be as follows:



To access elements in the array, an index must be used. After the index, the desired component would be specified. For example, to set values for the third student, the following statements could be used.

```
class(3)%name = "Fred"
class(3)%id = 4321
class(3)%score = 75.75
class(3)%grade = "C"
```

As with any array, the index can be an integer variable.

As with single variables, it is possible to assign all components of an array element to another array element or another variable of the same derived data type. The following declarations and code could be used to swap the location of the fifth student and the eleventh student.

```
type student
      character(50) :: name
      integer :: id
      real :: score
      character(1) :: grade
end type student

type(student), dimension(30) :: class
type(student) :: temp

temp = class(5)
```

```
            class(5) = class(11)
            class(11) = temp
```

This code fragment will copy all components from the fifth array element (of type type *student*) into a temporary variable (also of type *student*). Then, the eleventh array element can be copied into the fifth array element (thus overwriting all previous values). And, finally, the eleventh array element can be set of the original values from the fifth array element which are held in the temporary variable.

16.6 Example Two

In this example, we will write a simple program to perform some processing for students. The student information will be stored in an array of derived data types. There will be no more than 50 students per class. The main will call a subroutine to read student information (name and score) and another subroutine to set the student grades. Finally, the main will call a function to calculate the class average. The main will display the average. Routines for displaying the students are left as an exercise.

16.6.1 Understand the Problem

The main is expected to define the appropriate derived data type for student, declare some variables of that type and call the subroutines. The first subroutine will read student information including a name (up to 60 characters) and score from the user. Names and scores should continue to be read until a blank name is entered. The score value must be between 0.0 and 100.0 (inclusive). For this simple example, we will re-prompt for incorrect data entry (until correct data is provided). The routine must return the count of students entered. The second subroutine set the grades based on the following standard scale.

A	B	C	D	F
A>=90	80 - 89	70 - 79	60 - 69	<=59

When determining the final grade, the program should round up when appropriate. The main will call a function to calculate and return the average of the scores. Additionally, the main will display the final average.

16.6.2 Create the Algorithm

For this example main part for the main include declaration, display header, call read time subroutine, and the call the time summation subroutine. The basic steps for the main include:

```
            ! define derived data type for student
            !     must include → name, id, grade
            ! declare variables
            !     includes → array for up to 50 students
            ! display initial header
            ! call subroutine to read student information
            ! call subroutine to set grades
            ! use function to calculate average of scores
            ! display average
```

The basic steps for the read student information subroutine include:

```
! subroutine header and appropriate declarations
! loop
!     prompt for student name
!     read name
!     if name is empty, exit loop
!     loop
!           prompt for student score
!           read score
!           check score entered
!           if [ score is between 0.0 and 100.0 (inclusive) ] exit
!           display error message
!     end loop
!     update count of students
!     place values in student array
! end loop
```

The basic steps for the set grades subroutine include:

```
! subroutine header and appropriate declarations
! loop
!     read score / set grade
!           ≥ 90 → A; 80 - 89 → B; 70 – 79 → C; 60 - 69 → D; ≤ 59 → F
! end loop
```

When determining the final grade, the nearest integer intrinsic function, nint(), can be used to perform the appropriate rounding.

The basic steps for the calculate average score function include:

```
! function header and appropriate declarations
! loop
!     sum scores
! end loop
! calculate and return average
```

For convenience, the steps are written a program comments.

16.6.3 Develop the Program

Based on the algorithm, the below program could be developed.

```
program classScores
! define derived data type for student, includes → name, id, grade

implicit none
type student
      character(60) :: name
      real :: score
      character(1) :: grade
end type
```

```
! declare variables, including → array for up to 50 students
type(student), dimension(50) :: class
integer :: count
real :: average

! display initial header
      write (*,'(/,a,/)') "Student Information Example Program."

! call subroutine to read student information
      call readStudents (class, count)

! call subroutine to set grades
      call setStudentGrades (class, count)

! use function to calculate average of scores
      average = classAverage (class, count)

! display average
      write (*,'(/,a, f5.1)') "Final Class Average: ", average

contains

! *******************************************************
!  Subroutine to read student information (name and score).
!     A blank name will stop input
!     The score must be between 0.0 and 100.0 (inclusive)

subroutine readStudents (class, count)
type(student), dimension(50), intent(out) :: class
integer, intent(out) :: count = 0
character(60) :: tempname
real :: tempscore

      do
!     prompt for student name and read name
            write (*,'(a)',advance="no") "Enter Student Name: "
            read (*,'(a60)') tempname

!     if name is empty, exit loop
            if ( len_trim(tempname) == 0 ) exit

            do
!                 prompt for student score and read score
                  write (*,'(a)',advance="no") "Enter Student Score: "
                  read (*,*) tempscore

!                 check score entered
                  if ( tempscore >= 0.0 .and. tempscore <= 100.0 ) exit

!                 display error message
                  write (*,'(a,/,a)') "Error, invalid score.",   &
                              "Please re-enter time."

            end do
```

```
!           update count of students and place values in student array
            count = count + 1
            class(count)%name = tempname
            class(count)%score = tempscore

      end do

      return
end subroutine readStudents

! ********************************************************
!  Subroutine to set student grades.
!     ≥ 90 → A; 80 - 89 → B; 70 – 79 → C; 60 - 69 → D; ≤ 59 → F

subroutine setStudentGrades (class, count)
type(student), dimension(50), intent(inout) :: class
integer, intent(in) :: count
integer :: i

      do i = 1, count

!     read score / set grade
            select case ( nint(class(i)%score) )
                  case (90:)
                        class(i)%grade = "A"
                  case (80:89)
                        class(i)%grade = "B"
                  case (70:79)
                        class(i)%grade = "C"
                  case (60:69)
                        class(i)%grade = "D"
                  case (:59)
                        class(i)%grade = "F"
            end select

      end do

      return
end subroutine setStudentGrades

! ********************************************************
!  Function to calculate average score.

real function classAverage (class, count)
type(student), dimension(50), intent(in) :: class
integer, intent(in) :: count
integer :: i
real :: sum = 0.0

!     sum scores
      do i = 1, count
            sum = sum + class(i)%score
      end do

! calculate and return average
```

```
                classaverage = sum / real(count)

                return
        end function classAverage

        end program classScores
```

If the program does not work at first, the comments can aid in determining the problem.

16.6.4 Test/Debug the Program

For this problem, the testing would involve executing the and entering a series of student data values to ensure that the results are correct. If the the program does not provide the correct results, each of the subroutines and the function results should be verified individually. Each can be checked by displaying the intermediate results to the screen. In this manner, the subroutine or function that is not working correctly can be quickly identified. Once identified, some additional write statements inside the subprogram can be used to help identify the specific problem.

16.7 Exercises

Below are some quiz questions and project suggestions based on this chapter.

16.7.1 Quiz Questions

Below are some quiz questions.

1) An item in a derived data type is called?

2) How are components of a derived data type accessed?

3) Define a derived data type to store information about a circle. Must include a circle name (max 20 characters), size (radius – a real value) and the position in 3-dimensional space (***x***, ***y***, and ***z*** → all integer values).

4) Write the declaration necessary to declare two variables named ***circle1*** and ***circle2*** of type ***circle*** (from previous question).

5) Define a user-defined type, ***planet***, to store information for a planet. Include a name (15 characters), radius (real value), area (real value), and volume (real value). Additionally, write the declaration necessary to declare two variables named ***planet1*** and ***planet2*** of type ***planet***.

6) Define a user-defined type named ***date*** for processing dates consisting of a month name (10 characters), month (integer), day of month (integer), and year (integer).

7) Based on the previous question, write the statements to:
   a) declare a variable named ***today*** and set it to todays date → monthname (character), month, date, and year (integers)
   b) declare a variable named ***newyear*** and set it to January 1, 2011 → monthname (character), month, date, and year (integers)

16.7.2 Suggested Projects

Below are some suggested projects.

1) Type in the time summation program, compile and execute the program. Test on several sets of input including the example in the explanation.

2) Write a Fortran program to read and display information about about a set of planetary bodies. The program should read the information from a file, allow the use to select a display option, and call the appropriate routine to display that information.

   The main program should call a series of subroutines as follows:

   - Subroutine ***readPlanets()*** to prompt for file name of planets file, open the file (including error checking), and read file into an array. Three errors are allowed, but if a fourth error is made, the routine should terminate the program.
   - Subroutine ***calcPlanetArea()*** to calculate the planet area based on the diameters.
   - Function ***getUserOption()*** to display a list of options, read the selection option.
   - Subroutine ***displayPlanetMinMax()*** to display the minimum and maximum based on option as follows:
     - Option (1) → Smallest and Largest Planets (based on area)
     - Option (2) → Coldest and Hottest Planets (based on average temperature)
     - Option (3) → Planets with Shortest and Longest Days (based on day length)
   - Subroutine ***printPlanetsSummary()*** to display the planet name, distance from sun, and planet size.

   The output should be formatted as appropriate. Test on several sets of input values and verify that the output is correct for the given input values.

3) Modify the planet program (from previous question) to sort the planets based on the radius. Test on several sets of input values and verify that the output is correct for the given input values.

4) Type in the time class scores program, compile and execute the program. Test on several sets of input values.

5) Modify the class scores program to assign grades based on the following scale:

F	**D**	**C-**	**C**	**C+**	**B-**	**B**	**B+**	**A-**	**A**	**A+**
0-59	**60-70**	**70-72**	**73-76**	**77-79**	**80-82**	**83-86**	**87-89**	**90-92**	**93-96**	**97-100**

Test on several sets of input values and verify that the output is correct for the given input values.

6) Modify the class scores program to read the name and score file a file. Should include prompting for a file, opening the file, and reading the file contents into the class array. In order to complete this exercise, create a file containing some random names and scores. Test on several sets of input values.

17 Modules

For larger programs, using a single source file for the entire program becomes more difficult. Fortunately, large programs can be split into multiple source files, each file can contain a subset of subroutines and/or functions. There must be a main or primary source file that includes the main program. The secondary file or files is referred to as a module or modules. Additionally, the modules can then be more easily used in other, different programs ensuring that the code can be easily re-used. This saves time and money by not re-writing routines.

This section provided a description of the formatting requirements and an example of how to set-up the modules.

17.1 Module Declaration

The secondary source file or module must be formatted in a specific manner as follows:

```
module <name>
      <declarations>
contains
      <subroutine and/or function definitions>
end module <name>
```

For example, to declare a module named stats that includes some a function to find the average of the numbers in an array, the following module declaration might be used.

```
module stats
! note, no global variables used in this module

contains

! ************************************************************
!  Simple function to find average of len values in an array.

real function average(array, len)
real, intent(in), dimension(1000) :: array
integer, intent(in) :: len
integer :: i
      real :: sum = 0.0

      do i = 1, len
            sum = sum + array(i)
      end do
      average = sum / real(len)
end function average

end module stats
```

This example assumes the real array contains *len* number of values up to a maximum of 1000 values.

17.2 Use Statement

Once the module is defined, the routines from the module can be included by using the **use** statement. The use statement or statements must be at the beginning of the applicable source file. For example, below is a simple main that uses the previous stats module.

```
program average
use stats

implicit none
real, dimension(1000) :: arr
integer :: i, count
real :: ave

! -----
!  Initialize array with some values.

      count = 0
      do i = 1, 20
            arr(i) = real(i) + 10.0
            count = count + 1
      end do

! -----
!  Call function to find average and display result.

      ave = arraverage(arr, count)

      write (*, '(/, a, f10.2, /)') "Average = ", ave

end program average
```

The use statement is included before the variable declarations. Any number of use statements for defined modules may be included.

17.3 Updated Compilation Commands

For a large program that is split between multiple source files, the compilation process must be updated. The compilation process refers to the steps required to compile the program into a final executable file. Each module unit must be compiled independently. This allows the programmer to focus on one module, set of routines, at a time. Further, for very large projects, multiple programmers can work on separate modules simultaneously.

The initial step is to compile each module. Assuming the module from the earlier section is named **`stats.f95`**, the command to compile a module is:

```
gfortran -c stats.f95
```

which will read the source file (**`stats.f95`**) and create two new files; an object file **`stats.o`** and a module file **stats.mod**. The name of the object file is based on the name of the source file. The name of the module file is based on the module name. While they are the same name in this example, that is not a requirement.

The compile command is required for each module.

Once all the modules are compiled and the **.o** and **.mod** files are available, the main file can be compiled. This step reads the **.o** and **.mod** files for each module and builds the final executable file. For example, the command to compile the main file for the previous array average example is:

```
gfortran -o main main.f95 stats.o
```

For multiple modules, each of the **.o** files would be listed. In this example, the **stats.mod** file is read by the **gfortran** compiler. While not explicitly listed, the **.mod** files are required and used at this step.

17.4 Module Example Program

The following is an example program to compute the surface area and volume of a sphere. This is a fairly straightforward problem focusing more on the creation and use of a module for some routines.

17.4.1 Understand the Problem

This problem will be divided into two parts, the main program source file and a secondary source file containing the subroutines and functions. While this problem is not large enough to require splitting into multiple files, it is split to provide an example of how to use modules.

Recall that the formulas for the surface area and volume of a sphere are as follows:

$$surfaceArea = 4.0 * \pi * radius^2$$

$$volume = \frac{4.0 * \pi}{3.0} * radius^3$$

The value of **π** will be defined as a constant and set to 3.14159.

For this example, the main program will display some initial headers and read the radius from the user. Once the radius is read, the main program will call functions for the surface area and the volume and a subroutine to display the results.

17.4.2 Create the Algorithm

Based on the problem definition, the steps for the main are:

```
! display header and read radius
! call functions for sphere volume and surface area
! call routine to display formatted results
```

The module will contain the functions and subroutine. The first function will compute the sphere volume. The single step is:

```
! compute the volume of a sphere with given radius.
!     sphere volume = [ (4.0 * pi) / 3.0 ] * radius^3
```

The second function will compute the sphere surface area. The single step is:

```
! compute the volume of a sphere with given radius
!     sphere volume = 4.0 * pi * radius^2
```

The subroutine will display the formatted results.

17.4.3 Develop the Program

The program is presented in two parts corresponding to the main program and the secondary module routines. While this example is not really long or complex enough to require multiple files, the program is split in order to provide an example using a separate module file.

17.4.3.1 Main Program

Based on the algorithm, the below program could be developed.

```
program sphere
      use sphereRoutines

      implicit none
      real :: radius, spVolume, spSurfaceArea

! -----
!  Display header and read radius

      write (*,'(a/)') "Sphere Example Program"
      write (*,'(a)', advance="no") "Radius: "

      read (*,*) radius

! -----
!  Call functions for sphere volume and surface area

      spVolume = sphereVolume(radius)
      spSurfaceArea = sphereSurfaceArea(radius)

! -----
!  Call routine to display formatted results.

      call displayResults(radius, spVolume, spSurfaceArea)

end program sphere
```

The name of module, **sphereRoutines** in this example, must be the name of the secondary source file.

17.4.3.2 Module Routines

Based on the algorithms for the two functions and subroutine, the below module program could be developed. In this example, the declaration for **π** is defined as a global variable. This shares the variable between all the subroutines and functions in the module. Use of global variables is typically limited. This provided an example of an appropriate use of a global variable.

```
! Example secondary source file.

module sphereRoutines
implicit none                      ! needed in every module

! Global declarations, if any, go here.

real, parameter :: pi = 3.14159

! *******************************************************
!  Subroutines and functions are included after
!  the 'contains'.

contains

! *******************************************************
!  Compute the volume of a sphere with given radius.
!     sphere volume = [ (4.0 * pi) / 3.0 ] * radius^3

real function sphereVolume (radius)
real, intent(in) :: radius

      sphereVolume = ( ( 4.0 * pi ) / 3.0 ) * radius ** 3

end function sphereVolume

! *******************************************************
!  Compute the volume of a sphere with given radius.
!     sphere volume = 4.0 * pi * radius^2

real function sphereSurfaceArea (radius)
real, intent(in) :: radius

      sphereSurfaceArea = 4.0 * pi * radius ** 2

end function sphereSurfaceArea

! *******************************************************
!  Simple routine to display results.

subroutine displayResults(rad, vol, area)
real, intent(in) :: rad, vol, area

      write (*,'(/, a)') "-------------------------------"
      write (*, '(a)' ) "Results:"
      write (*,'(3x, a, f10.2)') "Sphere Radius = ", rad
      write (*,'(3x, a, f10.2)') "Sphere Volume = ", vol
```

```
            write (*,'(3x, a, f10.2, /)') "Sphere Surface Area = ", area

      end subroutine displayResults

      ! ********************************************************

      end module sphereRoutines
```

In a more complex program multiple module files might be used. The grouping should be based on the logical relationship of the routines. A more complicated program would require a more comprehensive design effort.

17.4.4 Test/Debug the Program

For this problem, the testing would involve executing the and entering a series of radius values and ensure that the results are correct. If the the program does not provide the correct results, each of the functions and the subroutines could be verified individually. Each can be checked by displaying the intermediate results to the screen. In this manner, the subroutine or function that is not working correctly can be quickly identified. Once identified, some additional write statements inside the subprogram can be used to help identify the specific problem.

17.5 Exercises

Below are some quiz questions and project suggestions based on this chapter.

17.5.1 Quiz Questions

Below are some quiz questions.

1) What is the primary purpose of using a module?
2) In the main program, what statement is used to include the modules?
3) How many main programs are allowed?
4) How many modules are allowed?
5) Is the **`contains`** key word needed in a module file (yes or no)?

17.5.2 Suggested Projects

Below are some suggested projects.

1) Type in the array average main program and the array average module, compile and execute the program. Test on several sets of input including the example in the explanation.
2) Type in the sphere volume and surface area main program and the sphere volume and surface area module, compile and execute the program. Test on several sets of input including the example in the explanation.
3) Update the planets program form the previous chapter, problem #2, and break the program into a main file and a module file for the functions and subroutines.

18 Appendix A – ASCII Table

This table lists the American Standard Code for Information Interchange (ASCII) characters or symbols and their decimal numbers.

Char.	Dec.
	32
!	33
"	34
#	35
$	36
%	37
&	38
'	39
(	40
)	41
*	42
+	43
,	44
-	45
.	46
/	47
0	48
1	49
2	50
3	51
4	52
5	53
6	54
7	55
8	56
9	57
:	58
;	59
<	60
=	61
>	62
?	63

Char.	Dec.
@	64
A	65
B	66
C	67
D	68
E	69
F	70
G	71
H	72
I	73
J	74
K	75
L	76
M	77
N	78
O	79
P	80
Q	81
R	82
S	83
T	84
U	85
V	86
W	87
X	88
Y	89
Z	90
[	91
\	92
]	93
^	94
_	95

Char.	Dec.
`	96
a	97
b	98
c	99
d	100
e	101
f	102
g	103
h	104
i	105
j	106
k	107
l	108
m	109
n	110
o	111
p	112
q	113
r	114
s	115
t	116
u	117
v	118
w	119
x	120
y	121
z	122
{	123
|	124
}	125
~	126
	127

19 Appendix B – Windows Start-Up Instructions

The following provides some specific instructions for getting started. These instructions are specifically geared for using a Windows based PCs. This includes all versions of Windows from Windows XP, Windows Vista, Windows 7, and Windows 8.

The basic process is very similar to MAC and Linux (which is not covered here).

19.1 Working Files

Before working with Fortran program files, you should decide where you will be working (C\: drive, USB drive, network drive, etc.) and create a working directory where your files will be placed. In general, it will be easier if your Fortran files are not mixed with other, unrelated files. This directory should be someplace you can easily get to it. That might be on your home workstation/laptop, on a network drive, or on a USB drive.

19.2 Obtaining The Compiler

First, you will need to download and install the GNU Fortran compiler. The main web page for the GNU Fortran compiler is:

http://gcc.gnu.org/fortran/

This page provides general information regarding the Fortran compiler development effort, project objectives, and current status.

More specific information, and the Windows compiler binaries, can be found on the gFortran Wiki page, which is located at:

http://gcc.gnu.org/wiki/GFortran

This page contains links to the Gfortran binaries. On this page, click on the link labeled:

Binaries for Windows, Linux, and MacOS

Which will display the page for the GNUBinaries for various platforms, including Windows, MacOS, and Linux. Click on the Windows link, which will show the various Windows options. For standard Windows (XP/Vista/7/8), the heading **MinGW build** ("native Windows" build), includes a link for the latest ***installer***. Click on the link and download the Windows installation program. You will need to access this file to perform the actual installation.

This version will work on all supported Windows versions including Windows 7 and Windows 8.

After downloading, install the compiler. The installation can be accomplished by double-clicking on the downloaded file. As with all Windows installs, it will require System Administrator privileges.

19.3 Command Prompt

In order to compile and work with programs under Windows, we will need to provide typed commands to the computer. This is done from within the "Command Prompt" utility.

19.3.1 Windows XP/Vista/7

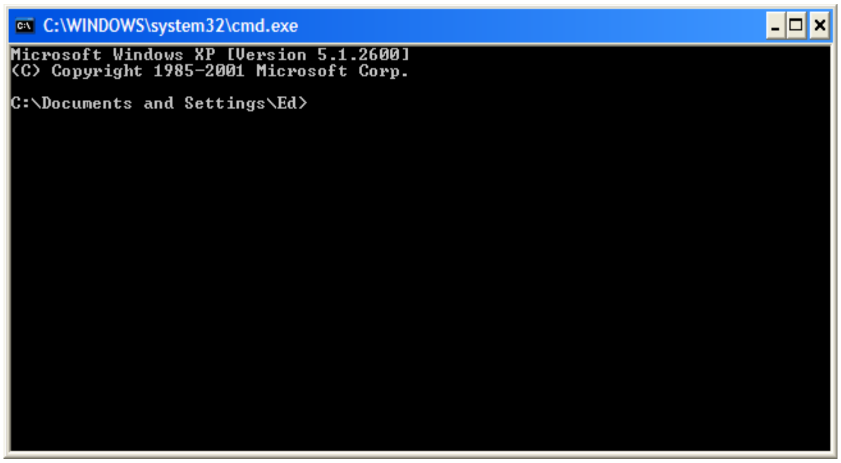
In For Windows 7, the "Command Prompt" is usually under **Programs** → **Accessories** → **Command Prompt**.

19.3.2 Windows 8

For Windows 8, the "Command Prompt" can be found by using Search and is listed under the **Windows System** heading.

19.3.3 Command Prompt Window

The open Command Prompt window for any Windows version will look similar to the following:



```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\Ed>
```

Once the Command Prompt is open, the device and directory for the working files can be set.

19.3.4 Device and Directory

In order to compile and work with programs under Windows, a working directory should be established. This is where the program files will be stored. First, establish the ***device*** of the working directory. If the files are on C:\ (the main hard drive), the device is already set. If the working directory is located on a network drive, alternate drive, or USB drive, the device will need to be set.

Using the "My Computer", determine the device or drive letter where you directory is located. Type that letter at the prompt in the Command Prompt window. For example, if your device is **K**, you would type "**k:**".

At the "K:\>" you will need to change directory into the directory where your files are (if you created one). The "cd <dir_name>" command can be used. For example, if the directory is named cs117, the command would be "**cd cs117**".

For example:

```
C:\Documents and Settings\Ed\My Documents> k:
K:\> cd cs117
```

At this point, typing **dir** (for directory) will provide a list of files in the directory. While the format will appear different, the files are the same as shown in the **My Computer** listing.

19.4 Compiler Installation Verification

To ensure the compiler is installed correctly, open the "Command Prompt", and type **gfortran** at the prompt.

```
K:\cs117> gfortran
gfortran: no input files
```

The "no input files" message means that the installation was completed correctly. It is not necessary to set the device or directory in order to perform this verification.

However, if the following message is displayed,

```
K:\cs117> gfortran
'gfortran' is not recognized as an internal or external command,
operable program or batch file.
```

means that the Fortran compiler is not installed. The installation issue must be addressed before continuing. Once the installation is completed successfully, the compilation steps detailed in Chapter 3 can be completed.

19.5 Compilation

Once the Fortran compiler is installed, programs can be compiled. Open the "Command Prompt", and set the device and directory as appropriate.

At this point the program can be compiled, using "gfortran. The optional "-o" qualifier is used to set the name of the output file. To execute, you can type the name of the executable (that was specified with the "-o").

To compile the example program, the following command would be entered:

```
K:\cs117> gfortran -o hw hw.f95
```

This command will tell the 'gfortran' compiler to read the file **hw.f95** and, if there are no errors, create an executable file named **hw.exe**. If there is an error, the compiler will generate an error message, sometimes cryptic, and provide a line number. Such errors are usually the result of mistyping one of the instructions. Any errors must be resolve before continuing.

19.6 Executing

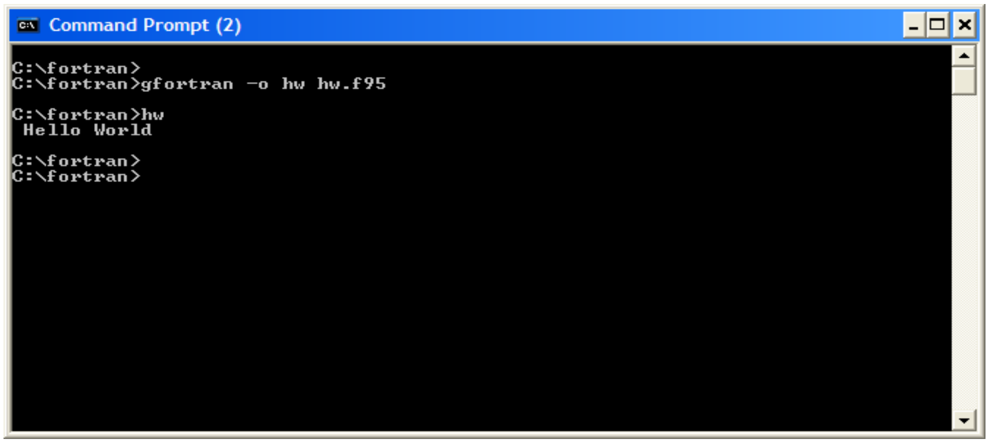
To execute or run a program, type the name of the executable file. For example, to execute or run the ***hw.exe*** program:

```
K:\cs117> hw
 Hello World
K:\cs117>
```

Which will execute the example program and display the "Hello World" message to the screen.

19.7 Example

A more complete example is as follows:



```
C:\fortran>
C:\fortran>gfortran -o hw hw.f95

C:\fortran>hw
 Hello World

C:\fortran>
C:\fortran>
```

It is not necessary to type the extension (i.e., ".exe") portion of the file name.

20 Appendix C – Random Number Generation

Generating random numbers is a common requirement for many problems. The following provides a summary of utilizing the built-in Fortran random number generator routines.

20.1 Initialization

The first step in generating random numbers is to initialize the Fortran random number generator, random_seed(). The most basic initialization is performed as follows:

```
call random_seed()
```

This will initialize the random number generator with a default seed. As such, each execution will re-generate the same series of random numbers for each execution. While this may not appear very random, since successive executions generate the same series of random numbers, the testing is more repeatable.

20.2 Generating Random Number

To request a random number, a real variable must be declared and then passed to the following call to the built-in random_number() routine. For example:

```
call random_number(x)
```

The random number between 0.0 and 1.0 such that 0.0 ≤ random number < 1.0.

In order to obtain a larger number, it can be multiplied by an appropriate scale. For example, to simulating the roll of a dice, a random integer number between 1 and 6 would be required. The following code would obtain the random number and then scale it and convert to integer as required.

```
call random_number(x)
die = int(x*6.0) + 1
```

Since the 0.0 is a possible value and 1.0 is not (0.0 ≤ random number < 1.0) 1 is added to ensure that 0 can not be assigned to the variable *die*. Further, since .999 is the largest possible value (since 1.0 is not), and .999 * 6 will generate 6 (5.9 truncated to 5 with 1 added).

20.3 Example

A simple example program to generate 1000 random integer numbers, each between 1 and 100, is as follows:

```
program rand

implicit none
integer, parameter :: rcount=1000
integer :: i
integer, dimension(rcount) :: nums
real :: x

      call random_seed()

      do i = 1, rcount
            call random_number(x)
            nums(i) = int(x*100.0) + 1
      end do

      write (*,'(a)') "Random Numbers:"
      do i = 1, rcount
            write (*,'(i3,2x)', advance="no") nums(i)
            if (mod(i,10)==0) write(*,*)
      end do

end program rand
```

The call to random_seed() must be performed before the call to random_number(). Additionally, the call to random_seed() can only be performed once.

The output of this example program is shown below:

```
Random Numbers:
100   57   97   75   37   49    8    1   35   35
 22   14   91   39   45   67    2   66   65   33
 86   41   21   97   60   68   46   34   11   76
 61   72   90   66   16   62   98  100   26   56
 66   56   98   91   66   73   41   93   15   68
 77   34   12   62   83   95   74   50   38   43
 56  100  100   75   96   10   74   76   95   71
 82   56    7   49   60   14   59   52   89   31
 67   67   51   27    8   11   55   38    2   80
 63   78   96   12   32   60    5   12   22   11
```

Each execution will generate the same series of random numbers.

20.4 Example

In order to generate different random number for successive executions, the seed must be initialized with a different set of seed values each time.

The following example simulates the roll of two dice, which requires two random integer numbers, each between 1 and 6.

```
program diceRoll

implicit none
integer :: m, die1, die2, pair
real :: x
integer :: i, n, clock
integer, dimension(:), allocatable :: seed
character(10) :: nickname

      call random_seed(size = n)
      allocate(seed(n))
      call system_clock(count=clock)
      seed = clock + 37 * (/(i-1, i=1, n)/)
      call random_seed(put = seed)
      deallocate(seed)

      call random_number(x)
      die1 = int(x*6.0) + 1

      call random_number(x)
      die2 = int(x*6.0) + 1

      write (*,'(2(a,1x,i1/),a,1x,i2)') "Dice 1:", die1,   &
                  "Dice 2:", die2, "Dice Sum", (die1+die2)

end program diceRoll
```

Will generate different values each execution. For example, three executions of the example program are shown below:

```
C:\fortran> dice
Dice 1: 5
Dice 2: 4
Dice Sum  9

C:\fortran> dice
Dice 1: 2
Dice 2: 4
Dice Sum  6

C:\fortran> dice
Dice 1: 1
Dice 2: 6
Dice Sum  7

C:\fortran>
```

The dice values will be different for each execution.

21 Appendix D – Intrinsic Functions

The following is a partial listing of the Fortran 95 intrinsic functions. Only the most common intrinsic functions are included in this section. A complete list can be found on-line at the GNU Fortran documentation web page.

21.1 Conversion Functions

The following table provides a list of intrinsic functions that can be used for conversion between different data types.

Function	Description
INT(A)	Returns integer value of real argument A, truncating (real part) towards zero.
NINT(X)	Return nearest integer value (with appropriate rounding up or down) of the real argument X.
REAL(A)	Returns the real value of integer argument A.

21.2 Integer Functions

The following table provides a list of intrinsic functions that can be used for integers.

Function	Description
ABS(A)	Returns integer absolute value of integer argument A.
MOD(R1,R2)	Return the integer remainder of integer argument R1 divided by integer argument R2.

21.3 Real Functions

The following table provides a list of intrinsic functions that can be used for reals.

Function	Description
ABS(A)	Returns real absolute value of real argument A.
ACOS(W)	Returns real inverse cosine of real argument W in radians.
ASIN(W)	Returns real inverse sine of real argument W in radians.
ATAN(X)	Returns real inverse tangent of real argument X in radians.
COS(W)	Returns real cosine of real argument W in radians.
LOG(W)	Returns real natural logarithm of real argument W. Real argument W must be positive.
MOD(R1,R2)	Return the real remainder of real argument R1 divided by real argument R2.
SIN(W)	Returns real sine of real argument W in radians.
SQRT(W)	Returns real square root of real argument W. Real argument W must be positive.
TAN(X)	Returns real tangent of real argument X in radians.

21.4 Character Functions

The following table provides a list of intrinsic functions that can be used for characters/strings.

Function	Description
ACHAR(I)	Returns the character represented by integer argument I based on the ASCII table (Appendix A). Integer argument I must be between 1 and 127.
IACHAR(C)	Returns the integer value of the character argument C represented by ASCII table (Appendix A).
LEN(STR)	Returns an integer value representing the length of string argument STR.
LEN_TRIM(STR)	Returns an integer value representing the length of string argument STR excluding any trailing spaces.
LGE(STR1,STR2)	Returns logical true, if STR1 ≥ STR2 and false otherwise.
LGT(STR1,STR2)	Returns logical true, if STR1 > STR2 and false otherwise.
LLE(STR1,STR2)	Returns logical true, if STR1 ≤ STR2 and false otherwise.
LLT(STR1,STR2)	Returns logical true, if STR1 > STR2 and false otherwise.
TRIM(STR)	Returns string based on the string argument STR with any trailing spaces removed.

21.5 Complex Functions

The following table provides a list of intrinsic functions that can be used for complex numbers.

Function	Description
AIMAG(Z)	Returns the real value of the imaginary part of the complex argument Z.
CMPLX(X,Y)	Returns complex value with real argument X and the real part and real argument Y as the imaginary part.
REAL(A)	Returns the real value of the real part of the complex argument Z.

21.6 Array Functions

The following table provides a list of intrinsic functions that can be used for arrays.

Function	Description
MAXLOC(A1)	Returns integer location or index of the maximum value in array A1.
MAXVAL(A1)	Returns maximum value in array A1. Type of value returned is based on the type of the argument array A1.
MINLOC(A1)	Returns integer location or index of the minimum value in array A1.
MINVAL(A1)	Returns minimum value in array A1. Type of value returned is based on the type of the argument array A1.
SUM(A1)	Returns sum of values in array A1. Type of value returned is based on the type of the argument array A1.

21.7 System Information Functions

The following table provides a list of intrinsic functions that obtain information from the system.

Function	Description
COMMAND_ARGUMENT_COUNT()	Returns the number of command line arguments.
GET_COMMAND_ARGUMNENT(NUMBER, VALUE, LENGTH, STATUS)	Returns command line arguments, if any. • NUMBER, integer argument of the number to return. Must be between 1 and COMMAND_ARGUMENT_COUNT(). • VALUE, character(*), Nth argument • LENGTH, integer, length of argument returned in VALUE • STATUS, integer, status, 0=success and -1=VALUE character array is too small for argument, other values=retrieval failed
CPU_TIME(TIME)	Returns the amount of CPU time expended on the current program in seconds. TIME is return as a real value.
DATE_AND_TIME (DATE, TIME,ZONE,VALUES)	Return date and time. • DATE(), character(8), string in the form YYYYMMDD, where YYYY is year, MM is month, and DD is date. • TIME(), character(10), string in the form HHMMSS.SSS where HH is hour, MM is minute, SS is second, and SSS is millisecond. • ZONE(), character(5), string in the form of ±HHMM, where HHMM is the time difference between local time and Coordination Universal Time. • VALUES(), integer array where ◦ VALUES(1) → year ◦ VALUES(2) → month (1-12) ◦ VALUES(3) → date (1-31) ◦ VALUES(4) → month (1-12) ◦ VALUES(5) → hour (0-23) ◦ VALUES(6) → Time zone difference (minutes) ◦ VALUES(7) → seconds (0-59) ◦ VALUES(8) → milleseconds (0-999) Each argument is optional, but at least one argument must be included

22 Appendix E – Visualization with GNUplot

The Fortran language does not have any built-in graphics capabilities. To support some basic data visualization a plotting application, GNUplot, can be used. GNUplot is a free, open source plotting program that can plot data files and display user-defined functions.

This appendix provides a very brief summary of some of the basic GNUplot functions as applied to plotting data from simple programs in this text. An general example program to plot a simple function is provided for reference.

22.1 Obtaining GNUplot

The first step is to obtain and install GNUplot.

GNUplot is available at,

```
http://www.gnuplot.info/
```

To ensure that GNUplot is installed correctly, for Windows machine, you can enter command prompt and type,

```
wgnuplot
```

which will start GNUplot by opening a new window. To exit, type **exit** at the prompt.

Complete documentation, tutorials, and examples are available at that site. Additionally, there are many other web site dedicated to GNUplot.

22.2 Formatting Plot Files

Since our specific use of GNUplot will involve plotting a data file created with a Fortran program, it will be necessary to provide some information and directions for GNUplot in the file. That information is provided in a header (first few lines) and a footer (last few lines). As such, the program must first write the header, write the data, typically in the form of data points to be plotted, and write a final footer. The header and footer may be very different based on what is being plotted.

22.2.1 Header

The header will provides some guidelines on how the output should look, including title (if any), axises (if any), lables (if any), and plotting color(s). Additionally, comments can be included with a "#" character. Comments are useful to provide information about the contents of the plot file or nature of the data being plotted. A typical header might be as follows:

```
# Example Plot File
set title "CS 117 Plot Function"
plot "-" notitle with dots linewidth 2 linecolor 2
```

Once the header is written, a series of data points can be written.

22.2.2 Footer

The footer is used to formally tell GNUplot there are no more points. Additionally, the "pause" directive can be used to ensure that any plots displayed from the command line are left on the screen. A typical footer might be as follows:

```
end
pause -1
```

Nothing after the footer will be read by GNUplot.

22.3 Plotting Files

In order to display a plot file on a Windows machine, at the command prompt, type,

```
wgnuplot file.plt
```

which will start GNUplot and instruct GNUplot to read the file "file.plt". The file name can be anything and the file extension is not required to be ".plt".

If the header or footer commands are incorrect or the data points are invalid, nothing will be displayed. To investigate, the file can be opened with a text editor.

22.4 Example

This section provides an example program that plots a simple function.

$$y = \sin(x) * \left(\frac{1 - \cos(x)}{3.0} \right)$$

The program, data file, and final output are presented for reference.

22.4.1 Plot Program

The following is an example program that generates points, opens a plot file, write the header, data points, and footer.

```
program plotExample

implicit none
real, dimension(200) :: x, y
integer :: i, opnstat

! Generate x and y points
      do i = 1, 200
            x(i) = i * 0.05
            y(i) = sin(x(i)) * (1-cos(x(i)/3.0))
      end do

! Output data to a file
      open (12, file="data.plt", status="replace",         &
                  action="write",   position="rewind",     &
                  iostat=opnstat)
      if (opnstat > 0) stop "error opening plot file."

! Write header
      write (12, '(a)') "# Example Plot File"
      write (12, '(a)') "set title ""Example Plot Function"" "
      write (12,'(a,a)') "plot ""-"" notitle with dots ",
                              "linewidth 2 linecolor 2"

! Write points to file.
      do i=1,100
            write(12,*) x(i), y(i)
      end do

! Write footer and close file
      write (12, '(a)') "end"
      write (12, '(a)') "pause -1"

      close(12)

end program plotExample
```

The data file name can be changed or read from the user.

22.4.2 Plot File

The output file this program appears as follows:

```
# Example Plot File
set title "Example Plot Function"
plot "-" notitle with dots linewidth 2 linecolor 2
  5.0000001E-02  6.9413913E-06
  0.1000000      5.5457884E-05
  0.1500000      1.8675877E-04
  0.2000000      4.4132397E-04
  0.2500000      8.5854460E-04
```

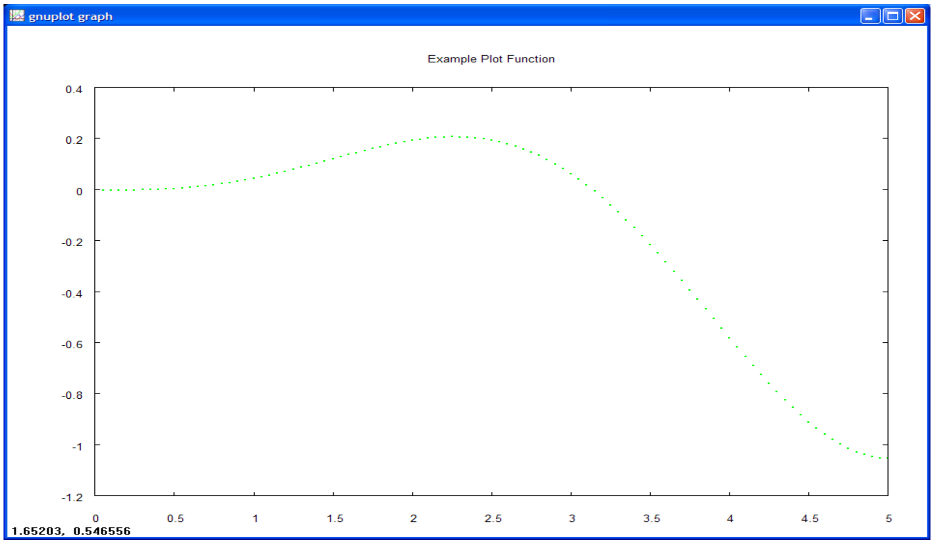
[*many points not displayed due to space considerations*]

```
   4.900000      -1.043852
   4.950000      -1.048801
   5.000000      -1.050716
end
pause -1
```

The output file can be edited with a standard text editor. This will allow checking the data file for possible errors if it does not display correctly.

22.4.3 Plot Output

The plot output is as follows:



On Windows machines, the plot can be printed by right clicking on the blue bar (on top). This will display a menu, with “Print” as one of the options.

23 Appendix F – Fortran 95 Keywords

In programming, a keyword is a word or identifier that has a special Fortran 95 meaning. Keywords are reserved in that they can not be used for anything else such variable names.

The ***Type*** as listed in the table refers to the following:

- statement → implies a keyword that starts a statement, usually one line unless there is a continuation "&"
- construct → implies multiple lines, usually ending with "end …"
- attribute → implies it is used in a statement to further clarify or specify additional information.

For reference, below is a partial list of keywords or reserved words. For a complete list of keywords, refer to the on-line GNU Fortran 95 documentation.

Keyword	Type	Meaning
allocatable	attribute	no space allocated here later allocate
allocate	statement	allocate memory space now for variable
assignment	attribute	means subroutine is assignment (=)
backspace	statement	back up one record
call	statement	call a subroutine
case	statement	used in select case structure
character	statement	intrinsic data type
close	statement	close a file
complex	statement	intrinsic data type
contains	statement	internal subroutines and functions follow
cycle	statement	continue the next iteration of a do loop
deallocate	statement	free up storage used by specified variable
default	statement	in a select case structure - all others
do	construct	start a do loop
else	construct	part of if, else if, else, end if
else if	construct	part of if, else if, else, end if
elsewhere	construct	part of where, elsewhere, end where
end do	construct	ends do loop
end function	construct	ends function

end if	construct	ends if
end interface	construct	ends interface
end module	construct	ends module
end program	construct	ends program
end select	construct	ends select case
end subroutine	construct	ends subroutine
end type	construct	ends type
end where	construct	ends where
endfile	statement	mark the end of a file
exit	statement	continue execution outside of a do loop
format	statement	defines a format
function	construct	starts the definition of a function
if	statement and construct	if(...) statement
implicit	statement	"none" is preferred to help find errors
in	a keyword for intent	the argument is read only
inout	a keyword for intent	the argument is read/write
integer	statement	intrinsic data type
intent	attribute	intent(in) or intent(out) or intent(inout)
interface	construct	begins an interface definition
intrinsic	statement	says that following names are intrinsic
inquire	statement	get the status of a unit
kind	attribute	sets the kind of the following variables
len	attribute	sets the length of a character string
logical	statement	intrinsic data type
module	construct	beginning of a module definition
namelist	statement	defines a namelist of input/output
nullify	statement	nullify a pointer
only	attribute	restrict what comes from a module
open	statement	open or create a file
operator	attribute	indicates function is an operator like +
optional	attribute	a parameter or argument is optional
out	a keyword for intent	the argument will be written

print	statement	performs output to screen
pointer	attribute	defined the variable as a pointer alias
private	statement and attribute	in a module
program	construct	start of a main program
public	statement and attribute	in a module - visible outside
read	statement	performs input
real	statement	intrinsic data type
recursive	attribute	allows functions and derived type recursion
result	attribute	allows naming of function result
return	statement	returns from exits subroutine or function
rewind	statement	move read or write position to beginning
select case	construct	start of a case construct
stop	statement	terminate execution of the main procedure
subroutine	construct	start of a subroutine definition
target	attribute	allows a variable to take a pointer alias
then	construct	part of if construct
type	construct	start of user defined type
use	statement	brings in a module
where	construct	conditional assignment
while	construct	a while form of a do loop
write	statement	performs output

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