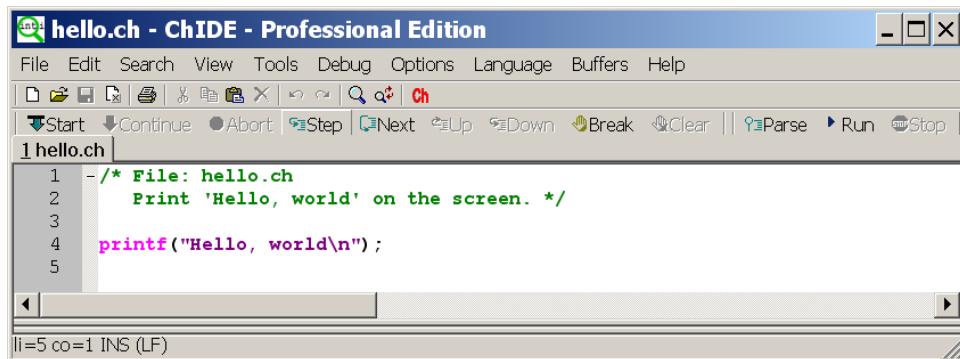


Learning Computer Programming with Ch for the Absolute Beginner

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The income generated from this book will go to the C-STEM fund to support the C-STEM program.

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PREFACE

Knowledge of computer programming is one of the most fundamental skills for today's K-12 students. Writing computer programs is essential to solving complex problems. Consequently, computer programming is becoming a necessary skill for many professions. C is one of the most popular computer programming languages. This manuscript is a gentle introduction to computer programming. It teaches absolute beginners the underlying working principles of computer programming using a user-friendly and pedagogically effective C/C++ interpreter Ch.

Prerequisites

The mathematical prerequisite for the manuscript is Pre-Algebra or concurrent enrollment, except for section 7.7 in **Chapter 7** which requires a trigonometry background. No prior computer or programming experience is required.

Special Features

The primary goal of this manuscript is to teach beginners without any prior programming experience the underlying working principles of computer programming and problem solving in C. It is designed for a one-term or one-year course, depending on the course schedule and other additional topics such as robotics programming, an introduction to computer programming for students in middle and high schools as well as colleges. Towards these goals, it is written with the following salient features:

- *Using a C/C++ interpreter Ch for teaching and learning.* Ch is a user-friendly interactive C/C++ computing environment especially designed for absolute beginners to learn computer programming and problem solving with computers. As a complete C interpreter, Ch conforms to the C standard. C expressions, statements, functions, and programs can be executed in Ch interactively without compiling and linking the code. It can be used for quick testing and trying difficult C features such as arrays, especially for classroom presentation and discussion sessions. ChIDE, a user-friendly Integrated Development Environment (IDE), can be used to execute functions and programs with detailed line-by-line traces. In this manuscript, many C code and statements are executed in the C/C++ interpreter Ch interactively with output to illustrate numerous programming features and concepts. C has a reputation for being difficult to learn and even more difficult to master. Ch will relieve your learning burden and make your programming tasks more enjoyable. More reasons for using Ch to teach and learn C/C++ are described in (<http://www.softintgeration.com/academic/WhyCh.html>).
- *Using a proven effective pedagogy. A single topic is presented in a section first and then reinforced and cross-referenced in other sections and chapters.* The manuscript is organized cumulatively. Each chapter builds on information presented in the earlier chapters. A chapter itself is organized cumulatively and each section uses information provided in the previous sections.
- *Plotting for visualization.* A picture is worth a thousand words. A plotting library is used for visualization and solving many practical problems in both the text and exercises. All plots including those in exercises in this manuscript were generated using simple functions in this plotting library.
- *Multiple versions for example programs.* Earlier example programs are gradually rewritten to make them more concise, efficient, powerful, useful, and user friendly. This way, students do not struggle with trying to understand new features and new programs at the same time.

- *Teaching and learning by examples.* Through a disciplined approach, various features of C, programming style, modular programming, code reuse, and algorithm development for solving practical problems are illustrated by approximately 70 well-documented complete sample programs.

Organization of the Manuscript

The topics in the manuscript are carefully selected and organized for the best information flow for beginners to learn how to solve real-world problems in C with practical and realistic application examples. The manuscript is organized as follows:

Chapter 1 uses a simple C program to begin computer programming in Ch.

Chapter 2 discusses the basic elements of a computer programming language and most commonly used data types. It also presents the mechanisms for input and output.

Chapter 3 presents operators and expressions.

Chapter 4 describes graphical plotting for applications.

Chapter 5 relational operations and selection statements for making decisions.

Chapter 6 describes loops for repetition and algorithm development using flowcharts.

Chapter 7 covers function for procedural programming, code reuse, and modular programming.

Chapter 8 uses arrays for data processing.

Chapter 9 deals with file processing. It describes how to write data into files and read data from files.

Chapter 10 describes how to make quick animation using QuickAnimation. The last section uses Ch with a loop to generate complicated animations. This chapter can be presented after students have learned loops in **Chapter 6** or functions in **Chapter 7**.

Appendix A describes how to create and use function files in Ch. **Appendix B** lists keywords and brief Ch language references used in this book. **Appendix C** lists the glossary for terminologies used in the book.

In the beginning of each section, the **Prerequisites**, applicable **Common Core Content Standards** and **California Career Technical Education (CTE) Model Curriculum Standards**, and learning **Objectives** are listed. The end of each chapter contains a section **Chapter Summary**. Programs in the book showcase good programming practices. However, good programming styles and practices are further emphasized in the subsection **Programming Tips**. Bad programming styles and common programming errors are also described in this section. The subsection **Terminology** summarizes all terminologies and topics presented in the chapter.

Symbols and Notations Used in the Book

This book was typeset by the author using L^AT_EX. Programs in the book are displayed with the light blue background and syntax highlighting as shown in the following line of the code.

```
printf("Hello, world!\n");
```

The output from programs are displayed with the grey background as shown in the following output.

```
Hello, world!
```

The interactive execution of programs is displayed with the dark blue background as shown in the following interactive execution.

```
Enter the weight in ounces.  
4.5  
The ice cream costs $2.11
```

Special notes and important points are highlighted with the yellow background. Keywords such as **int** and **double** in C are in red color. Reserved words such as **sqrt** and **printf** are in pink color. The **definition** for a word is in green color.

Sections marked with the double dagger symbol ‘†’ use Algebra I and Trigonometry concepts. They can be skipped as they do not include prerequisite skills necessary for later chapters.

The dangerous bend symbol  indicates computations that may display incorrect results if they are not entered correctly.

The exercise symbol  indicates the location to pause for students to solve problems in the exercise section.

A Note to Instructors

Depending on the teaching objectives and pace, not all chapters need to be covered. For example, for a four-week introduction to computer programming in a Technology course, only the first three chapters may be covered. For a semester course, only the first five chapters may be covered. For one semester or one year high school course on computer programming, additional topics such as robotics, Web programming, or hardware interface may be added. In this case, please contact the author for supplementary materials.

An instructor should use a computer and projector to make presentations in a classroom and run sample programs described in each section using ChIDE. We recommend that you adopt the dual programming teaching method as described in the next section for this curriculum. *It is suggested that students complete all exercises in each section.*

Dual Programming

It has been long recognized in introductory computer science courses that students working in pairs are more successful than students working independently. The most common and successful model for such collaborative work is *Pair Programming*. In this model the pair shares one computer with one student acting as the “driver” writing the code and using the computer, and the other partner becoming the “navigator”, checking the work of the driver and suggesting ways to complete the programming exercises. The partners regularly switch roles so that both share the responsibility for the work. While this might be an excellent model for college students there are some key features that would be problematic in a K-12 setting. In particular the student filling the role of the navigator is likely to become disengaged with the work and it is very easy for one student to dominate the partnership. Because of this it is recommended that a slightly different model called Dual programming be implemented.

Dual Programming is a collaborative learning technique pioneered by the UC Davis C-STEM Center and its K-12 partners. Using dual programming two students work together, each with their own computer to complete a programming assignment. Both partners must have completed an assignment before either one is allowed to move on to later exercises. As they are working, partners compare their source code, discuss the differences, and support each other in the debugging process.

By making these simple adjustments to the pair programming model, dual programming maximizes the amount of time that each student spends engaged with the computer. This in turn enhances students ownership of the work they complete as well as individual accountability. Together these elements make it more likely for each student to attain a higher level of content mastery, while at the same time maintaining the benefits of increased confidence from their partnership as well as improved work quality. In addition partners are not only seeing examples of another students code, but actively engaging in critiquing each others work.

In order to maximize the benefits it is recommended that students be placed into heterogeneous groups that can be dynamically adjusted. This allows groups to be modified should a particular partnership prove unsuccessful. Such groupings are beneficial to both partners as students of differing abilities are equally capable of recognizing troublesome syntax errors and provide an extra level of security to each others coding process. Additionally, heterogeneous grouping provides a solid scaffolding structure for students who need such support. The necessary discussions that accompany this method develop both partners effective communication habits, a critical 21st century skill.

Dual programming has the ultimate effect of increasing student confidence, accuracy and understanding. Equally important, the ability for students to rely on each other to find and correct each others errors enables the teacher to focus their time on student teams that are struggling with the content.

Available Teaching Resources

To use this manuscript for teaching, instructors can contact the author to obtain related teaching materials, including the source code for all programs presented in this manuscript, PowerPoint slides for classroom presentation, and solutions for exercises. Students can download and install Ch Student Edition from <http://www.softintegration.com> in their own computers.

Acknowledgments

Many K-12 educators contributed to the development of this book. Spencer Krautkraemer, Chris Schlesselman, Joe Stymeist, Heidi Espindola, Francesca DeFazio, and Megan Schoellhamer provided me with the guidance and suggestions on the topic selection and organization of the book. Spencer Krautkraemer, Chris Schlesselman, Joe Stymeist, and Francesca DeFazio scrutinized the text and programs with countless suggestions. Their suggestions especially helped make the book more appealing to learners in K-12 schools. Joe Stymeist helped write the prologue titled Prerequisite, Common Core Content Standards, CTE Model Curriculum Standards, and Objective at the beginning of each section. Heidi Espindola and Ryan Mangan helped compile the glossary. Spencer Krautkraemer, Chris Schlesselman, and Joe Stymeist helped develop PowerPoint slides for classroom presentation. Finally, I would like to thank Clay Dagler for his contribution in helping develop Chapter 10.

I am grateful for all their support and contributions. However, I take the full responsibility for any errors.

Contacting the Author

I appreciate any criticisms, comments, identification of errors in the text or programs, and suggestions for improvement of this manuscript from both instructors and students. I can be reached over the Internet at

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Harry H. Cheng

CHAPTER 1

Getting Started with the First Ch Program

1.1 Introduction

The computer is one of the most important inventions of the 20th century. Computers have a profound impact on our lives and play an important role in our society. For example, computers control our transportation systems, electric power systems, telephone systems, student records in schools, bank accounts, etc. But, what is a computer and how does it work?

A **computer** is a machine that manipulates data based on a list of instructions called a **program**. A computer can process information and perform mathematical calculations much faster than human beings. A program, installed on a computer, tells the computer when to obtain information, how to process information and perform calculations, and what output to produce. Instructions of a program are executed by a **central processing unit (CPU)**, which is also commonly referred to as a **microprocessor**.

Robots, cellular phones, microwave ovens, and other electronic devices typically contain an on-board embedded computer. As an example, with a program running on a robot's computer, the robot can make intelligent decisions and take actions based on external sensory information (what it sees, hears, and feels around itself). A computer or robot serves only the programmed commands. When a computer or robot does something smart, it is because a smart person has written a smart program to control the device.

C is the language of choice for writing programs for billions of embedded systems that interact with hardware. C and its variant, C++, are also the languages of choice for writing games, Web browsers, word processors, and most programs that run on your PC. This book teaches you how to write your own programs so that a computer or robot will do what you want it to do.

An **interpreter** is a program that executes programs written in a programming language directly. **Ch** is a C/C++ interpreter invented by Harry H. Cheng. It is specially designed for the absolute beginner to learn computer programming. It can be conveniently used to execute C or C++ programs. In this manuscript, all programs will be executed using this C/C++ interpreter.

In this chapter, we will use a simple program to present some important and basic features of the com-

1.2. Getting Started with ChIDE

puter programming language. Each statement of the sample programs will be explained. You will learn how to execute C programs, statements, and expressions in Ch interactively.

1.2 Getting Started with ChIDE

An Integrated Development Environment (IDE) can be used to develop computer programs. ChIDE is an IDE to develop C/Ch/C++ programs. ChIDE, as shown in Figure 1.1, can be easily launched by double

clicking its icon  on the desktop. A Ch Command Shell can be conveniently launched by clicking the red-colored **Ch** icon on the desktop.

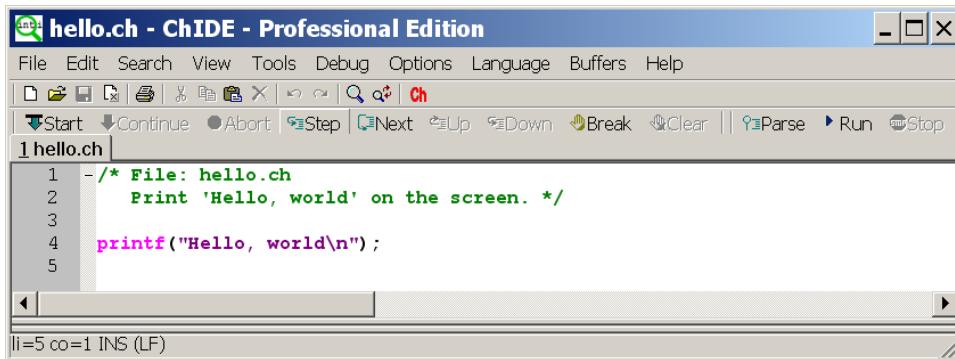


Figure 1.1: A program displayed in ChIDE.

1.2.1 The First Ch Program

Let's get started with programming in Ch! We will write a simple program shown in Program 1.1.

```

/* File: hello.ch
Print 'Hello, world' on the screen. */

printf("Hello, world\n");

```

Program 1.1: The first Ch program `hello.ch`.

This program will display the following output on the screen when it is executed:

```
Hello, world
```

To run the code in Program 1.1, the source code needs to be written first. **Source code** is plain text, which contains instructions of a program. If the text in Program 1.1 is typed in the editing pane in ChIDE, the program will appear colored due to syntax highlighting and with line numbers, as shown in Figure 1.2.

We will explain each line in Program 1.1 in detail. Contents that begin with `/*` and end with `*/` are comments. The symbol `//` can also be used inside a program to comment out a subsequent text at the end of a line. **Comments** are used to document a program to make the code more readable. When comments are processed by Ch, they are ignored and no action is taken relating to the comments. The first two lines, listed below, in Program 1.1 are comments.

1.2. Getting Started with ChIDE

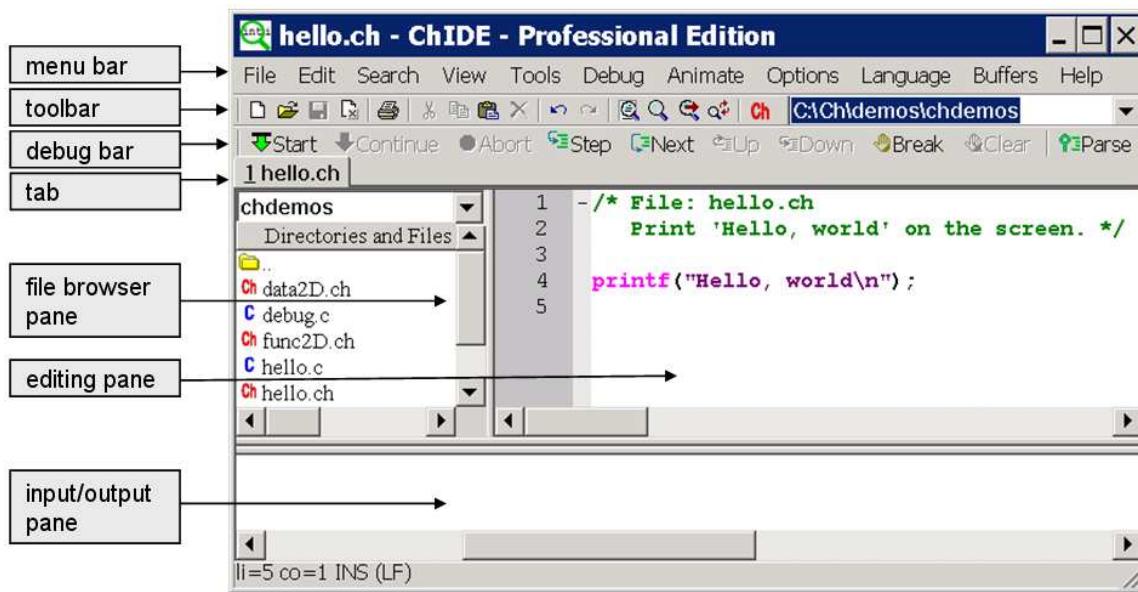


Figure 1.2: A layout and related terminologies in ChIDE.

```
/* File: hello.ch
   Print 'Hello, world' on the screen */
```

They document that the file name of the program is `hello.ch` and the purpose of the program is to print the message `Hello, world` on the screen.

A Ch program typically ends with “.ch”, which is called the **file extension**. A file name generally does not contain a space.

Function is the basic executable module in a program. Asking a function to perform its assigned tasks is known as **calling** the function.

In the statement

```
printf("Hello, world\n");
```

The function `printf()` is used to display `Hello, world` on the screen. The symbol `\n` will be explained in section 1.3.

Each statement in a program must end with a semicolon. However, when a statement is entered in a Ch Command Shell, the ending semicolon is optional as illustrated in the previous sections.

All programs presented in this manuscript are available in the distribution of the source code for this manuscript.

1.2.2 Editing Programs

Text editing in ChIDE works similarly to most Windows or Mac text editors, such as Word for creating documents.

As an example, open a new document by clicking the command `File->New` on the menu bar or the first icon on the toolbar that looks like a little piece of paper with a folded corner, as shown in Figure 1.2. Type the text in Program 1.1 in the editing pane in ChIDE. The program appears colored due to syntax highlighting and with line numbers.

You can save the document as a file named `hello.ch` by the command `File->Save As`. Follow the instruction and type the file name `hello.ch` to save as a new program. You can also right click the

1.2. Getting Started with ChIDE

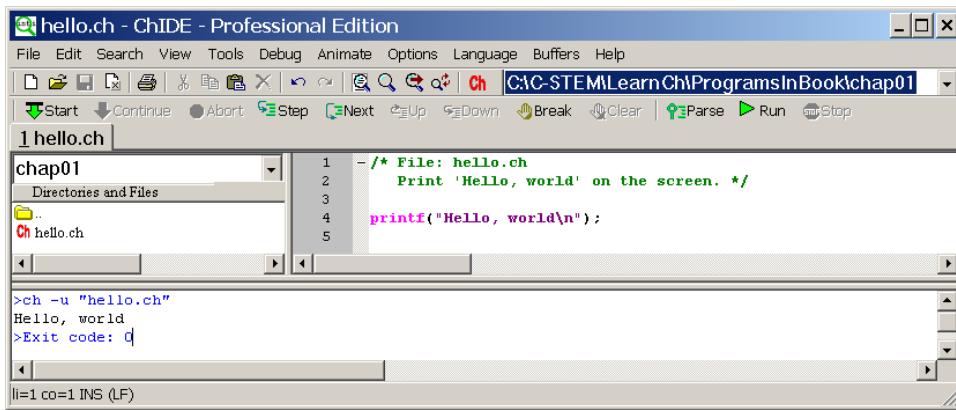


Figure 1.3: Running the program inside the editing pane in ChIDE and its output.

file name on the tab bar, located below the debug bar, and then select the command **Save As** to save the program.

1.2.3 Running Programs and Stopping Their Execution

Click **Run** on the toolbar, as shown in Figure 1.3, to execute the program `hello.ch`. This will cause the interpreter to read the code and provide an output on the bottom of the ChIDE window as shown in Figure 1.3. Pressing the function key **F2** will also execute the program. If you are editing a program, pressing **F2** will save the edited program first and then run the saved program.

If the command execution has failed or execution is taking too long to complete, then the **Stop** command on the toolbar can be used to stop the program.

1.2.4 Output from Execution of Programs

The **editing pane** on the top is for writing and editing a program source file or any text file. The **input/output pane** is located below the editing pane, and is initially hidden. It can be made larger by dragging the divider between it and the editing pane. The output from the program is directed into the input/output pane when it is executed using the command **Run**, as shown in Figure 1.3. When the program `hello.ch` is executed, the input/output pane will be made visible if it is not already visible and will display the following three lines, as shown in Figure 1.3.

```
>ch -u "hello.ch" // use the command ch for Ch to execute hello.ch
Hello, world      // the output from executing the program hello.ch
>Exit code: 0     // display the exit code for the program
```

An exit code of 0 indicates that the program has terminated successfully. If a failure had occurred during the execution of the program, the exit code would be -1.

The input/output pane can be opened and closed by the command **View->Output Pane**.

Do Exercises 2 and 3 on page 10.

1.2. Getting Started with ChIDE

1.2.5 Correcting Errors in Programs

ChIDE can identify errors that occur in C source code and provide helpful responses that aid the user in finding and correcting these errors. To see this, we will create an error in the program `hello.ch` by changing the line

```
printf("Hello, world\n");
```

to

```
printf("Hello, world\n";
```

Notice that in the second statement the closing parenthesis is missing. When the program is executed, the results should look like the input/output pane in Figure 1.4. The line with incorrect syntax in the editing pane and the corresponding error message in the input/output pane are highlighted with a yellow background.

Because the program fails to execute, the exit code `-1` is displayed at the end of the input/output pane as

```
>Exit code: -1
```

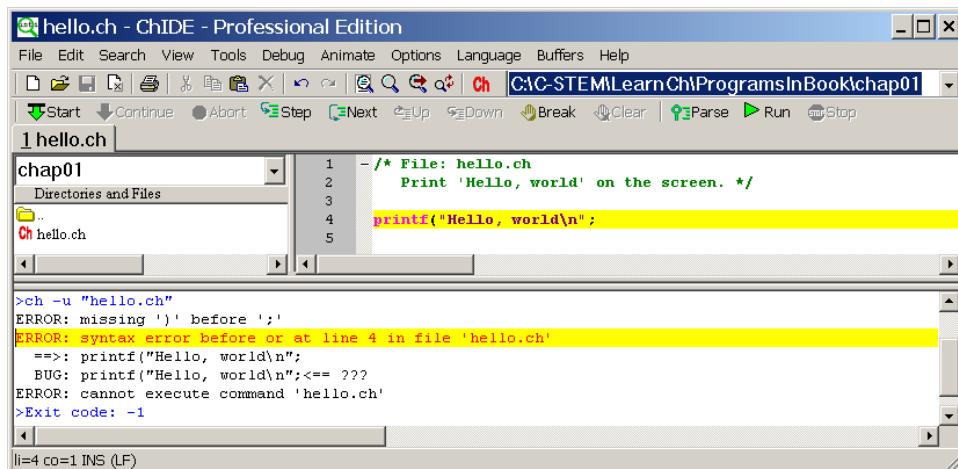


Figure 1.4: The error line in output from executing program `hello.ch`.

Errors in computer programs are called **bugs**. The process of finding and reducing the number of bugs is called **debug** or **debugging**. ChIDE is especially helpful for testing and debugging programs. It has a variety of tools that aid users with identifying and correcting errors, which will be discussed more thoroughly in section 2.4 in Chapter 2 and section 7.2 in Chapter 7.

Do Exercise 4 on page 10.

1.2.6 Browsing Files

All programs described in the book are available in a folder in `C:\C-STEM` for Windows, `/opt/C-STEM` for Mac OS X, `/usr/local/C-STEM` for Linux. If you use a computer in a laboratory, you may not have permission to write in this folder. You may copy these programs in your own folder.

In Windows, you can hover the cursor over the program name on the tab, the full path and program name will be displayed, as shown in Figure 1.5. This is useful to find out where the program is located when you open multiple programs.

1.3. Executing Programming Statements and Expressions in Ch

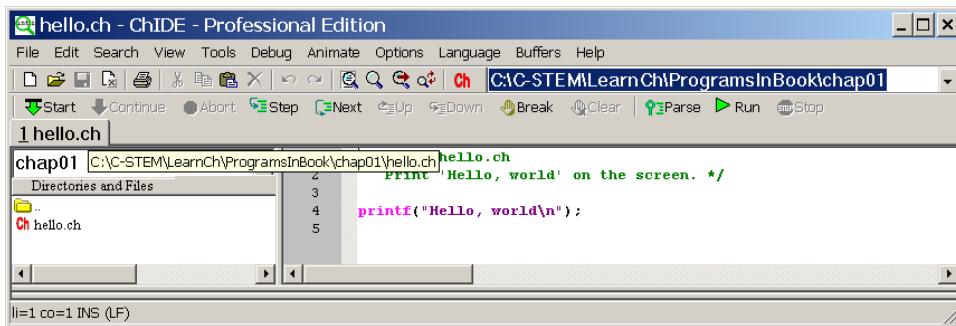


Figure 1.5: Displaying the full path of a program.

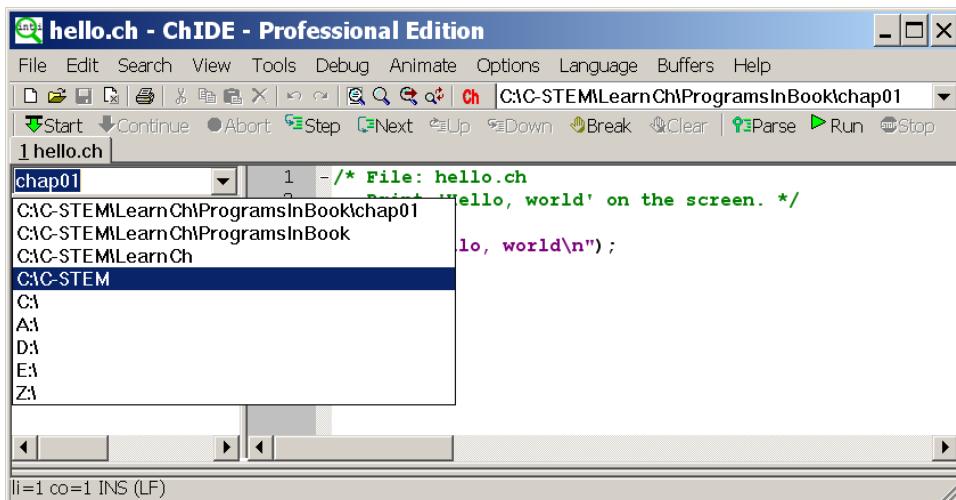


Figure 1.6: Displaying the parent directories of the current working directory.

Programs in the current working directory are displayed in the file browser pane, as shown in Figure 1.2. The current working directory is displayed at the end of the tool bar and also at the top of the file browser pane. The first entry under **Directories and Files** in the file browser pane is the parent directory of the current working directory. Clicking the arrow at the end of the current working directory in the file browser pane, all parent directories of the current working directory are displayed as shown in Figure 1.6. Selecting a parent directory, its contents will be displayed in the file browser pane.

The history of current working directories can be displayed by clicking the arrow at the end of the tool bar as shown in Figure 1.7. Selecting a directory in the history of the current working directories, the selected directory will become the current working directory and its contents will be displayed in the file browser pane.

1.3 Executing Programming Statements and Expressions in Ch

Ch can be used as a **command shell** or **Command Shell** in which commands are processed.

A Ch Command Shell can be conveniently launched by clicking the red-colored **Ch** icon on the desktop

1.3. Executing Programming Statements and Expressions in Ch

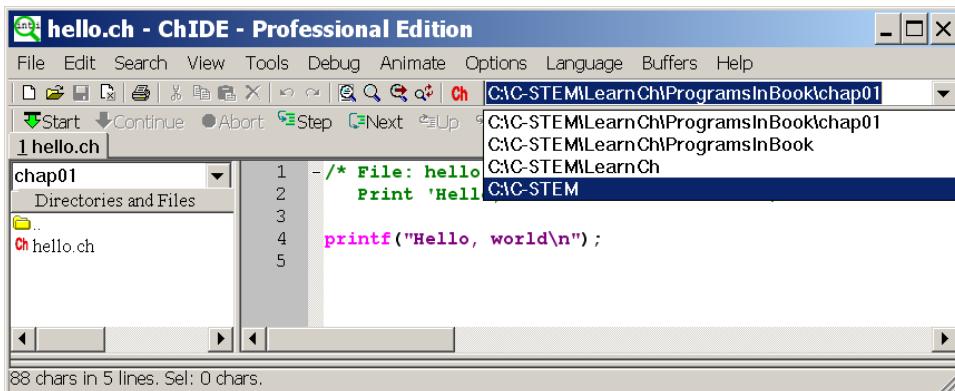


Figure 1.7: Displaying the history of current working directories.

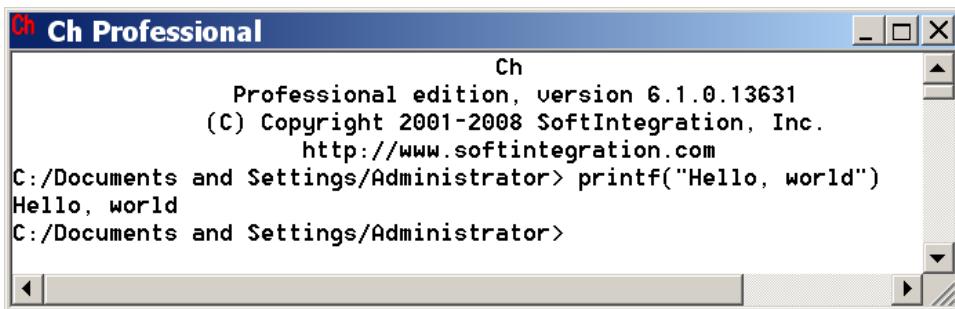


Figure 1.8: A Ch command shell.

or on the toolbar of the ChIDE.

After a Ch shell is launched in Windows, by default, the screen prompt of the shell window becomes

```
C:/Documents and Settings/Administrator>
```

where C:/Documents and Settings/Administrator is the user's **home directory** on the desktop as shown in Figure 1.8. The colors of the text and background as well as the window size and font size of the shell window can be changed by right-clicking the Ch icon at the upper-left corner of the window, and select the Properties menu to make changes (Note that for Windows Vista and Windows 7, you need to run ChIDE with the administrative privilege to make such a change.) The displayed directory C:/Documents and Settings/Administrator is also called the **current working directory**. If the user is not the administrator, the account name **Administrator** will be changed to the appropriate user account name.

If you are using a version of Unix, like Mac OS X, the prompt may show:

```
/home/harry>
```

where /home/harry is the home directory for the user with the account name harry.

The prompt > indicates that the system is in a Ch shell and is ready to accept input from keyboard. If you type in a command correctly, it will be executed successfully. Upon completion of the execution, the system prompt > will appear again. If an error occurs during the execution of the program or expression, the Ch shell will print an error message to assist the user in solving the problem.

Unlike other command shells, C programs, functions, statements, and expressions can be readily executed in a Ch command shell. You can try utilizing different features of C/C++ quickly as shown in this section.

1.3. Executing Programming Statements and Expressions in Ch

1.3.1 Interactive Execution of Programming Statements and Expressions

Any statements or expressions that you can use with C can also be typed into the Ch command shell directly. Any output from the statements will be displayed on the screen. For example typing the line

```
printf("Hello, world")
```

directly in the Command Shell results in the following output.

```
C:/Documents and Settings/Administrator> printf("Hello, world")
Hello, world
```

Note that the semicolon at the end of a statement in a C program is optional when executed in a Ch command shell. There is no semicolon in calling the function `printf()` in the above execution. For simplicity, only the prompt `>` that occurs at the end of the *current working directory* in a Ch command shell will be displayed in the remaining presentation.

The symbol `\n` used in the function `printf()` in Program 1.1 means a *newline character*. It instructs the computer to start writing on a new line, like the `Enter` key, which can be illustrated by

```
> printf("Hello, world\nWelcome to C!")
Hello, world
Welcome to C!
```

After the newline character, the string `Welcome to C!` is displayed at the beginning of a new line on the screen.

 Do Exercises 5 and 6 on page 10.

If a C expression is entered, it will be evaluated by Ch. The result will then be displayed on the screen. For example, if the expression `1+3*2` is typed, the output will be `7` as shown below:

```
> 1+2*3
7
```

Because any valid C expression can be evaluated in the Ch shell, Ch can be conveniently used as a calculator. The Ch shell follows the correct order of arithmetic operations on any expression.

 Do Exercise 7 on page 10.

1.3.2 Repeating Commands in Ch Command Window

The most convenient way to repeat commands at the prompt is to use arrow keys on the keyboard. The previously typed commands can be retrieved by the up '`↑`' and down '`↓`' arrow keys for commands typed before and after the current command, respectively. The retrieved command can be modified by first moving the cursor to a position using the left '`←`' or right '`→`' arrow keys on the keyboard. Then, use the delete or backspace key to delete characters or type any characters to insert the characters for command line editing. After completing all desired alterations, press the `Enter` or `Return` key to display the new outcome.

For example, retrieve the previous command of `1+2*3` by using the up '`↑`' arrow key. Move the cursor to the position for '`2`', use the backspace key to delete the character '`+`', insert the character '`-`', press the `Enter` key to evaluate the expression `1 - 2 * 3`. You should get an output of `-5`.

 Do Exercise 8 on page 10.

Throughout this textbook, many programming features will be presented by executing C statements and expressions in Ch interactively.

1.4 Documentation about ChIDE and Ch Command Window

More information about running C and C++ programs in Ch using ChIDE can be obtained online by clicking Help on the menu bar. You can find a PDF file for ***ChIDE User Guide*** entitled “*Getting Started with ChIDE and Ch Command Shell*.”

1.5 Chapter Summary

1.5.1 Programming Tips

Good Programming Practice

1. Do not insert a space next to a parenthesis. For example, use

```
printf("Hello, World!\n");
```

instead of

```
printf( "Hello, World!\n" );
```

Common Programming Errors

1. Missing a semicolon at the end of a statement. For example,

```
printf("Hello, World!\n")           // bad
printf("Hello, World!\n");          // good
```

2. Missing one or both of the double quotes surrounding the format control string in a **printf()** function.
For example,

```
printf("Hello, World!);           // bad
printf("Hello, World!" );         // good
```

1.5.2 Terminology

General Concepts

administrator	arguments	calling
bugs	called function	character string
calling function	Ch	debugging
current working directory	debug	function
escape character	file extension	home directory
IDE	library	newline character
reserved keywords	text editor	Ch
C	C++	microprocessor
central processing unit (CPU)	interpreter	
program		

1.6. Exercises

Ch Reserved Words

```
\n
printf()
```

ChIDE Related Concepts

chide	Change Font Size	ChIDE
debug command pane	debug pane	editing pane
file browser pane	input/output pane	

1.6 Exercises

1. If you have your own computer, install C/C++ interpreter Ch Student Edition for Windows from the companion CD or download the latest version for different platforms from the Internet at <http://www.softintegration.com>.
2. Launch a Ch Command Shell. In the Ch Command Shell, type the command **cd** as shown below.

```
> cd
```

It will display your home directory. What's your home directory? Create a folder named **learnch** in your home directory to keep C programs that you will develop. You may use other folder name and location that your instructor specifies.

3. Write a program **welcome.ch** to print

```
Hello, world.
Welcome to Ch!
```

Use the command **File->New** or click the first menu on the toolbar in ChIDE to open a new edit buffer and enter your code for the program. The program calls the function **printf()** four times, one for each output line. Save your program as **welcome.ch** using the command **File->Save As** in the folder created in Exercise 2. Execute the program in ChIDE by the command **Run**.

4. Modify the above program **welcome.ch** to introduce a bug by removing a closing parenthesis ')'. Run the modified program in ChIDE by pressing the function key F2. Double click the displayed error message in the red color to find the corresponding line with the error. Run the program again by pressing the function key F2. Press the function key F4 to find the line corresponding to the first error message. Then, fix the bug.
5. If you use Mac OS X or Linux, in a Ch Command Shell, type

```
> ch -d
```

to copy the user start-up configuration file **.chrc** from CHHOME/config directory to your home directory, where CHHOME is the home directory for Ch, such as **/usr/local/ch**. This file contains some useful default settings.

6. Write a program **welcome2.ch** to print the same output as that from the program **welcome.ch** developed in Exercise 3. But, the program **welcome2.c** shall call the function **printf()** *only once*. Use the command **File->New** or click the first menu on the toolbar in ChIDE to open a new edit buffer and enter your code for the program. Save your code as the program **welcome2.c** and execute it in ChIDE.
7. Calculate the following mathematical expression in a Ch Command Shell:

- | | |
|-----------------|---------------------------------|
| (a) $2 * 3$ | (b) $(4 + 3 * 2) * 3.14$ |
| (c) $2 * 3 * 7$ | (d) $(4 - 3 * 2) * (2 + 3 * 2)$ |

8. First, calculate the expression $2 + 3 * 5$ in a Ch Command Shell. Then, retrieve the command and edit it to calculate the expression $2 + 4 * 5$.

CHAPTER 2

Variables, Data Types, and Input/Output

In this chapter, how variables are used to solve problems with unknown values will be described. Declaration of variables is presented first. Commonly used data types are then described. Finally, the input to and output from a program are also presented.

2.1 Commonly Used Data Types and Declaration of Variables

Prerequisite: None

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D2.1, D2.3

Objective: Identify the different kinds of commonly used data types in a C program and summarizes needs for these differences. Demonstrate the process of declaring and initializing variables before they are used.

Various data types can be used to represent different data or information in C programs. In this introductory book, only the most commonly used data types, as shown in Table 2.1, will be described. The data types **int**, **double**, and **string_t** are used to represent integers, floating-point numbers, and strings. Floating point numbers are used when a decimal is needed.

Variables are often used in solving problems with unknown values. Using variables to represent mathematical notation makes a program easier to modify and read. Variables can be used inside a C program. However, a variable has to be declared and associated with a proper data type before it can be assigned a

2.1. Commonly Used Data Types and Declaration of Variables

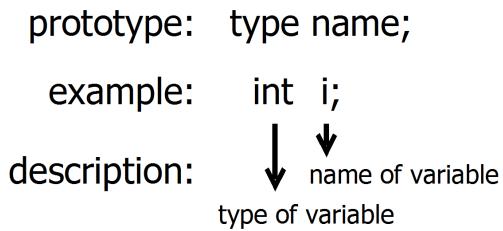


Figure 2.1: A general format for declaring a variable and an example.

value. In the subsequent sections, declaration and use of variables involving commonly used data types are explained.

Table 2.1: Commonly used data types and their usage.

Data Type	Usage	Examples
int	integers	12
double	floating-point numbers	123.4567
string_t	strings	"abc123"

2.1.1 Declaration of Variables and Integral Type **int**

An *identifier* is a sequence of lowercase and uppercase letters, digits, and underscores. Generally, a variable has to be declared before it can be used inside a program. As shown in Figure 2.1, a variable is declared by specifying its data type and identifier in the form

type name;

where *type* is one of the valid data types, such as **int**, **double**, or **string_t**, and *name* is a valid identifier. For example, the statements

```
int i;      /* declare variable i */
int num;    /* declare variable num */
```

declare variables *i* and *num* of **int** type. In this case, **int** is a keyword as a declarator for an integer data type and *i* and *num* are identifiers as variable names.

Rules for creating identifiers will be outlined next. The difference between lowercase and uppercase letters is important. In other words, variables are case sensitive. The initial character of an identifier must not be a digit. A reserved word, such as **int** and **return**, cannot be used as an identifier. To make the code more readable and portable, standard identifiers used for implementation of the C standard features can not be redefined by the user. For example, the identifier **printf** for the printing function name in the C standard input/output library shall not be redefined by the user. Table 2.2 shows some invalid identifiers for the user.

Multiple variables of the same type can be declared in a single statement by a list of identifiers, each separated by a comma, as shown below for two variables *i* and *num* of **int** type.

```
int i, num; // declare variables i and num
```

2.1. Commonly Used Data Types and Declaration of Variables

Table 2.2: Examples of invalid identifiers.

Invalid identifier	Reason
int	reserved word
double	reserved word
for	reserved word
2times	starts with a digit
integer#	character # not allowed
girl&boy	character & not allowed
class1+class2	character + not allowed
<hr/> Identifiers reserved for C implementation <hr/>	
printf	standard function name
scanf	standard function name

The symbol // comments out any subsequent text located on the same line.

For a software project, typically about 80 percent of the effort and cost are spent on the maintenance (updating and modifying) of the program after the original development is finished. A program is often maintained by someone other than the original developers. Using meaningful and consistent identifiers for variable names makes a program easier to understand, develop, and maintain. A variable name typically uses lowercase letters. For example, to calculate the position of a robot in a small program, one may use the identifier `s` for position to be consistent with the symbol used in the mathematical formula. For a large program with many variable names, one may use the identifier `pos` or `position` for the position. For a variable declared with a short name, a comment can be added to make the code more readable. A function name, such as `printf`, typically contains more than four characters to make the meaning of the function more descriptive at the point where the function is called. If an identifier contains two or multiple words, one can use an underscore to separate words or use an uppercase letter for the first character of the subsequent words. For example, to distinguish the position of a train from that of a bus, one may use `posTrain`, `pos_train`, `trainPos`, or `train_pos` for the position of a train.

The names `i`, `j`, `k`, `m`, `n`, `num`, and `count` are used in common practice for variables of `int` type.

2.1.2 Initialization

Assigning a value to a declared variable for the first time is called **initializing the variable**. You can initialize a variable in the same statement in which it is declared or you can initialize it in a separate statement. For example:

```
int j = 2; // declare j int type and initialize it with 2
```

and

```
int j; // declare j int type
j = 2; // initialize j with 2
```

accomplish the same goal of declaring an integer `j` and initializing it to 2.

 Do Exercises 1 and 2 on page 32.

2.1. Commonly Used Data Types and Declaration of Variables

2.1.3 Floating-Point Numbers and Type `double`

Floating point numbers are what we call real non-integer numbers in programming. For our purposes, a floating point number means a decimal. These numbers can be stored in a variable of **double** type in C. For example;

```
double x=10.5;
double y;
y = 3+x;
```

The names `x`, `y`, `z`, `length`, `width`, `radius`, and `speed` are used in common practice for variables of **double** type to hold decimal numbers.

Application: Calculating the Position of a Robot

Problem Statement:

A robot travels at the constant speed of 0.25 meter per second. The initial position of the robot is 1.25 meters. The position of this robot can be expressed as follows:

$$p = 0.25t + 1.25$$

where p is measured in meters from the origin and t is time in seconds. Therefore, if you want to know where the robot is at any time, you will take the number of seconds and multiply that by 0.25. Take that result and add 1.25 to the position of the robot before it started moving. The position $p(t)$ is a function of time t . Let's write a program to calculate the position when t is 10 seconds.

We will examine the source code for this program step-by-step. We will need some variables in the program to represent variables in the equation $p = 0.25t + 1.25$. Since the values for position and time can be decimals we will declare them both as **double** types.

```
double p; /* position */
double t; /* time */
```

We also know that we are looking at the problem when 10 seconds have passed, or $t = 10$, so we can initialize the variable `t` in the program.

```
t = 10.0; /* we use 10.0 to highlight that t is a double,
           10 could also be used */
```

Our program now looks like:

```
/* declare variables */
double p; /* position */
double t; /* time */

/* initialize variable t */
t = 10.0;
```

To make our program actually do something, we need to tell it how to calculate the position p , but this is the purpose of the equation:

```
p = 0.25*t + 1.25;
```

2.1. Commonly Used Data Types and Declaration of Variables

Note that C does not recognize proximity as multiplication. The multiplication operator '*' is needed for a multiplication operation.

Finally, we want to show the answer to the user by calling the function `printf()` similar to how we used it in `hello.ch` in Program 1.1. There are some additional features needed for this `printf()` function that will be explained in section 2.2.1. For now, accept that "%lf" is replaced by the value of the variable `p`.

```
printf("Position = %lf meters\n", p);
```

Thus, the final source code will look like Program 2.1. The printed output from running the program will be as follows.

```
Position = 3.750000 meters
```

```
/* File: posvar.ch
   Calculate the position of a moving vehicle
   using variables */

/* declare variables */
double p;    /* position */
double t;    /* time */

/* initialize variable t */
t = 10.0;

/* calculate the position */
p = 0.25*t + 1.25;

/* display output */
printf("Position = %lf meters\n", p);
```

Program 2.1: Calculating the position using variables.

In Program 2.1, for simplicity and consistency with the mathematical notations, the variables `p` and `t` represent the position and time, respectively. Comments for these variables are added in the declaration of these variables to make their intended use more clear. For a large program, we could declare variables with the names `pos` or `position` and `time` to make them more descriptive. Using variables to represent mathematical notations make a program easier to modify and more readable. It is especially helpful for solving problems with complicated logic.

 Do Exercise 3 on page 32.

2.1.4 Strings

A **character string** or **string** is a sequence of characters enclosed in double quotes, as in "xyz". A double quote " in a string shall be represented by the escape sequence \" as shown in Table 2.3. Strings are very useful. For example, the first argument in the function `printf()` is a string.

String type in Ch can be declared with the keyword **string_t** in the following format:

```
string_t s; // declare s as a string
s = "abc123";
```

2.2. Formatted Input and Output

Table 2.3: The commonly used character escape code.

Escape code	Translation
\a	(alert) Produce an audible beep or visible alert.
\n	(newline) Move the active position to the initial position of the next line.
\\\	(backslash) Produce a backslash character \.
\"	(double quote) Produce a double quote character ".

In the above code, the variable s is declared a string type and assigned the value of the string "abc123".

A string can also be initialized with a string value in the following form.

```
string_t name="John"; // initialize name with "John"
```

Escape Characters

Some special characters and particular behaviors of the output device are impossible to be typed directly in a source program. C uses *escape characters*, which are *escape codes* beginning with the backslash character '\', to represent these characters and behaviors. The most commonly used *character escape code* are listed in Table 2.3. You can try these escape characters in a Ch Command Shell as follows:

```
> printf("\a")           // alarm '\a'

> printf("abcd\nefg")    // newline '\n'
abcd
efg
> printf("abcd\"efg")   // double quote '\"'
abcd"efg
> printf("abcd\\efg")    // backslash '\\'
abcd\efg
```

2.2 Formatted Input and Output

Prerequisite: Understanding of variable types

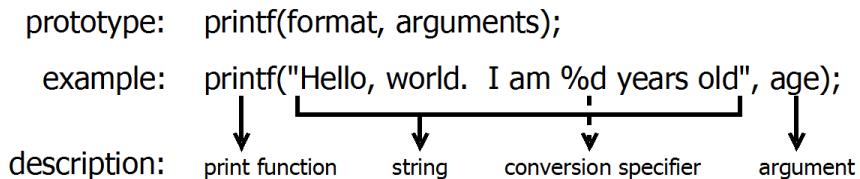
Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D2.1, D2.2

Objective: Chooses the proper C statements that allow formatted input and output to/from standard devices.

The **input/output**, or **I/O**, refers to the communication between a computer program and input/output devices. The inputs are the data received by the program. The outputs are the data produced by the program. In the previous section, we used the output function **printf()** to display the output from the program **hello.ch**, as shown in Figure 1.3, and the program **posvar.ch** in Program 2.1. In this section, we will learn more about the output function **printf()** as well as the input function **scanf()**.

2.2. Formatted Input and Output

Figure 2.2: A format for using the function **printf()** and an example.**2.2.1 The Output Function **printf()****

The function **printf()** can be used to print text and data to the computer screen. A general form of the function **printf()** and a sample application are shown in Figure 2.2. The **format** in the first argument is a string. This format string can contain an object called a conversion specifier, such as "%d" and "%lf". A **conversion specifier** tells the program to replace that object with the value of the expression of specific type that follows the string. The expression can be a constant or variable. For instance, in Program 2.1 the line

```
printf("Position = %lf meters\n", p);
```

contains the conversion specifier "%lf" which is replaced with the value of variable **p** when the program is run. The printed output thus becomes:

```
Position = 3.750000 meters
```

Table 2.4 lists the conversion specifiers we will use along with the data type they represent. The conversion specifier "%d" is used to print an integer number or the value of a variable of **int** type. The conversion specifier "%lf" is used to print a decimal number or the value of a variable of **double** type. The conversion specifier "%s" is used to print a string.

Table 2.4: Conversion specifiers for the functions **printf()** and **scanf()**.

Data Type	Format
int	"%d"
double	"%lf"
double	"%g"
string.t	"%s"

Examples below print an integer, decimal, and string.

```
> printf("%d", 10)           // integer
10
> printf("%lf", 12.345)       // decimal
12.345000
> printf("%s", "This is a string") // string
This is a string
```

The conversion specifier "%lf" prints out a decimal with six digits after the decimal point.

For conversion specifier "%g", the display style used is dependent on the value to be converted. An exponential display might be used for very a small or large number. Thus, for floating-point 12.345, the value displayed is in floating-point form. For value 12.0, the output is represented in an integer. For value 12345678.9, however, the printed value is in exponential form. These are shown in an interactive execution below.

2.2. Formatted Input and Output

```
> printf("%g", 12.345)
12.345
> printf("%g", 12)
12
> printf("%g", 12345678.9);
1.23457e+007
```

This conversion specifier is useful when you want to display the value of a variable in an integer when it is a whole number.

Using the wrong conversion specifier will give an incorrect result. For example, using "%d" for the decimal number 12.345 and "%lf" for the integer 10 will give incorrect results as shown below.

```
> printf("%d", 12.345)      // use %d for decimal
-687194767                 // incorrect result
> printf("%lf", 10)        // use %lf for integer
0.000000                   // incorrect result
```

In the examples below, values of variables of **int**, **double**, and **string_t** types are printed by the function **printf()**.

```
> int i = 12
> printf("i is %d", i)
i is 12
> double f = 12.345
> printf("f is %lf", f)
f is 12.345000
> string_t name = "John"
> printf("name is %s", name)
name is John
```

Multiple Conversion Specifiers

You can use more than one conversion specifier to print more than one value in a single printing statement. Each conversion specifier corresponds to an argument. The first conversion specifier corresponds to the first number following the string, the second conversion specifier for the second number following the string, and so forth. For example, one integer and one decimal number are printed in a single statement below:

```
> printf("integer is %d, decimal number is %lf", 10, 12.345)
integer is 10, decimal number is 12.345000
```

The first conversion specifier "%d" in the format string corresponds to the first number 10. The second conversion specifier "%lf" is for the second number 12.345.

Precision of Decimal Numbers

As pointed out before, by default, the conversion specifier "%lf" prints out a decimal number with six digits after the decimal point. When a decimal number is used to represent currency, we want to have two digits after the decimal point for cents. We can accomplish this by specifying the precision of the output. The **precision** of a decimal number specifies the number of digits after the decimal point. The precision typically takes the form of a period (.) followed by an integer. For example, the conversion specifier "%.2lf" specifies the precision with two digits after the decimal point, as shown below.

```
> printf("%.2lf", 12.1234)
12.12
> printf("%.2lf", 12.5678)
12.57
```

The number after the specified amount is rounded to the nearest value. For example, the floating-point number 12.1234 is printed as 12.12 with the precision value of 2, whereas 12.5678 is printed as 12.57.

2.2. Formatted Input and Output

Application: Calculating the Cost for Buying the Lemonade

Problem Statement:

The sale price of lemonade is \$1.29 per cup. Write a program to calculate the cost of buying 3 cups of lemonade.

In Windows, a program listed under the Windows explorer can also be dragged and dropped on to the ChIDE, which will open the program in the editing pane. You can open the file posvar.ch by dragging and dropping it on to the ChIDE first. Then copy the file posvar.ch in Program 2.2 to create a new program lemonade.ch by the command File->Save As. Finally modify the program, as shown in Program 2.2, to calculate the cost for buying lemonade.

```
/* File: lemonade.ch
   Calculate the cost for 3 cups of lemonade.
   The lemonade is sold by the cup. $1.39 per cup. */

/* declare variable cups for number of cups */
int cups;
/* declare variables price and cost */
double price, cost;

/* initialize cups and price */
cups = 3;           // number of cups
price = 1.29;       // $1.29 per cup

/* calculate the cost*/
cost = price * cups;

/* display the cost as output */
printf("%d cups of lemonade cost %.2lf \n", cups, cost);
```

Program 2.2: Calculating the cost for lemonade.

The math formula to calculate the cost of buying the lemonade at \$1.29 per cup is

$$\text{cost} = \text{price} * \text{cups}$$

$$\text{cost} = 1.29 * \text{cups}$$

Because we sell the lemonade by the cup, the variable `cups` can be declared as the `int` type. The other variables need to be declared as the `double` for decimal numbers. The code fragment below in Program 2.5 declares three variables `cups`, `price`, and `cost` first. It then assigns the numbers 3 and 1.29 to the variables `cups` and `price`, respectively. Finally, it calculates the cost.

```
int cups;           // number of cups
double price;      // price per cup
double cost;        // cost of the sale
cups = 3;           // number of cups
price = 1.29;       // price for each cup
cost = price * cups; // cost is calculated
```

2.2. Formatted Input and Output

Both cups and cost are displayed using the following statement with the function `printf()`.

```
printf("%d cups of lemonade cost $%.2lf \n", cups, cost);
```

The conversion specifier "`% .2lf`" is used to print the cost to the nearest cent, two digits after the decimal point. The output of Program 2.2 is as follows:

```
3 cups of lemonade cost $3.87
```

 Do Exercise 4 on page 32

2.2.2 The Input Function `scanf()`

The input function `scanf()` is used to input data from the keyboard so that the same program can be used to solve the same problems with different data. The conversion specifiers for the function `scanf()` are the same for the function `printf()` in Table 2.4. The conversion specifier "`%d`" can be used in the function `scanf()` in the form of

```
scanf("%d", &n);
```

for a variable `n` of the `int` type. The other conversion specifiers can be used for variables of other data types accordingly. For example, the statement

```
scanf("%lf", &x);
```

can be used to accept the user's input of a decimal and store it in the variable `x` of the `double` type. Since a variable of `double` type can also be used to store an integer. The user can also input an integer for the above input statement.

```
> int n
> double x
> string_t name
> scanf("%d", &i)      // accept an integer and store it in n
10
> i
10
> scanf("%lf", &x)      // accept a decimal and store it in x
15.6
> x
15.6000
> scanf("%lf", &x)      // accept an integer and store it in x
15
> x
15.0000
> scanf("%s", &name) // accept a string and store it in name
John
> name
John
```

The symbol ‘`&`’ is called the **address operator**. It tells the computer to get the address of the variable in the program. This has the effect of telling the computer to store the user input in that variable. This is why each call for the function `scanf()` has the address operator in front of the variable that will be used to store the input.

Multiple Conversion Specifiers

Like for the function `printf()`, the format string for the function `scanf()` can also contain multiple conversion specifiers to obtain the user input for multiple arguments by calling the function only once. For example, the code below let the user input two numbers and store them in variables `x` and `y` of `double` type.

```
double x, y; // declare variables x and y
scanf("%lf%lf", &x, &y); // input two numbers into x and y
```

Application: Calculating the Area of Rectangles

Problem Statement:

The area of a rectangle of length l and width w , as shown in Figure 2.3, is given by the formula

$$a = l * w$$

(a) Find the area in meters interactively with the length and width from the user input in a Ch Command Shell. (b) Write a program `rectanglearea.ch` to calculate the area of a rectangle with the length and width from the user input by calling the function `scanf()` only once. Test your code with 3 meters for l and 2.5 meters for w .

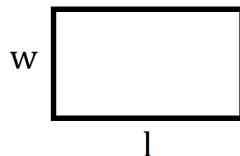


Figure 2.3: A rectangle with length l and width w .

Interactive execution of the commands in a Ch Command Shell is shown below.

```
> double l, w
> printf("Please input the length and width of a rectangle")
Please input the length and width of a rectangle
> scanf("%lf%lf", &l, &w)
3 2.5
> printf("The area of the rectangle is %lf square meters", l*w)
The area of the rectangle is 7.500000 square meters
```

The statement

```
scanf("%lf%lf", &l, &w);
```

accepts the user's input for length and width of a rectangle, and stores them into two variables `l` and `w` of `double` type.

2.2. Formatted Input and Output

```
/* File: rectanglearea.ch
   Calculate the area of a rectangle by calling scanf() only once. */

double l, w, area; /* length, width, and area */

printf("Please input the length and width of a rectangle in meters\n");
scanf("%lf%lf", &l, &w);

/* calculate the area */
area = l*w;

/* display the result */
printf("The area of the rectangle is %lf square meters\n", area);
```

Program 2.3: Calculating the area of a rectangle with the length and width from the user input by calling the function **scanf()** only once.

Most commands in a Ch Command Shell can be placed in the program `rectanglearea.ch` as shown in Program 2.3. For a rectangle of length 3 meters and width 2.5 meters, a sample interactive execution of the program `rectanglearea.ch` should appear as follows:

```
Please input the length and width of a rectangle in meters
3 2.5
The area of the rectangle is 7.500000 square meters
```

In this execution, the values 3 and 2.5 for the length and width of a rectangle are entered from the user. Note that a space is included between them. The output indicates that the area is 7.5 square meters.

 Do Exercises 5 and 6 on page 32.

Application: Greeting the User

Problem Statement:

Write a program `greeting.ch` to greeting the user.

2.3. Structures of a Program for Solving Applied Problems

```
/* File: greeting.ch
   Greet the user to computing */
/* variable name can hold up to 32 characters */
string_t name;      // declare name as a string

/* get the user input */
printf("What's your name?\n");
scanf("%s", &name);           // accept the user's input of a string

/* program output */
printf("Hello %s\n", name);
printf("Welcome to the wonderful computing world.\n");
printf("Enjoy your computing!\n");
```

Program 2.4: Greeting the user.

The program `greeting.ch` in Program 2.4 illustrates how strings are used in a program interactively. The statement

```
string_t name;      // declare name as a string
```

declares the variable `name` as a string. The statement

```
scanf("%s", &name); // accept the user's input of a string
```

uses the conversion specifier "`%s`" to accept a user's input for a name. The same conversion specifier is used in the following output statement.

```
printf("Hello %s\n", name);
```

A sample interactive execution of the program `greeting.ch` appears as follows:

```
What's your name?
John
Hello John
Welcome to the wonderful computing world.
Enjoy your computing!
```

In this execution, the string `John` for the name is entered after the prompt `What's your name.`

 Do Exercise 7 on page 32.

2.3 Structures of a Program for Solving Applied Problems

Prerequisite: Understanding variable types

Common Core Content Standards: L.6.6, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2

Objective: Identify the four sections that make up the structure of a Ch program.

2.3. Structures of a Program for Solving Applied Problems

As shown in programs in the previous section, the structure of a program for solving applied problems typically consists of the following four sections:

Declaration	Variables are given types (double , int , or string_t)
Initialization	Variables are given values
Processing	Calculation using variables
Termination	Final output

Variables are first declared. They are then initialized or assigned values from the user input. Next, they are used for data processing and computation. Finally, in the termination phase, the result will be printed. The concept of the program structure can be further illustrated by the following application example.

Application: A Lemonade Shop with Sales Tax

Problem Statement:

Write a program for a Lemonade Shop to process the sale of lemonade. The sale price for lemonade is \$1.29 per cup. The sales tax is 8.25 percent.

If the number of `cups` of lemonade is known, we can calculate the total cost by the math formulas as follows:

```
price = 1.29           // $1.29/cup
taxrate = 0.0825       // 8.25% (8.25 percent) sales tax
subtotal = price * cups // cost before tax
tax = taxrate * subtotal // sales tax
total = subtotal + tax   // total cost with tax
```

The 8.25 percent sales tax is changed to a decimal 0.0825 before multiplying with the subtotal to find the tax amount. With the above algebraic equations, Program 2.5 can be used to process the purchase of lemonade.

2.3. Structures of a Program for Solving Applied Problems

```

/* File: lemonade2.ch
   Calculate the cost with sales tax for a Lemonade Shop */

/* declare variables */
int cups;
double price, taxrate, subtotal, tax, total;

/* fixed price and tax rate */
price = 1.29;           // $1.29 per cup
taxrate = 0.0825;        // 8.25% (8.25 percent) sales tax

/* get the user input for the value of the variable cups */
/* '%%' will print out one '%' */
printf("Welcome to Mary's Lemonade Shop\n");
printf("We sell lemonade by the cup, $1.29 per cup with 8.25% sales tax.\n");
printf("Please enter the number of cups.\n");
scanf("%d", &cups);

/* process the order */
subtotal = price * cups;      // cost before tax
tax = taxrate * subtotal;     // sales tax
total = subtotal + tax;       // total cost with tax

/* display the cost as output */
printf("Subtotal: $%.2lf\n", subtotal);
printf("    Tax: $%.2lf\n", tax);
printf("    Total: $%.2lf\n", total);
printf("Thank you.\n");

```

Program 2.5: Using the function `scanf()` to process an order of purchase with sales tax.

Declaration: The program declares one variable `cups` of `int` type and five variables `price`, `taxrate`, `subtotal`, `tax`, and `total` of `double` type.

Initialization: When the program is executed, it will initialize the variables `price` and `taxrate` by the statements

```

price = 1.29;           // $1.29/cup
taxrate = 0.0825;        // 8.25% (8.25 percent) sales tax

```

Then, the program will first display

```

Welcome to Mary's Lemonade Shop
We sell lemonade the by the cup, $1.29 per cup with 8.25% sales tax.
Please enter the number of cups.

```

 The conversion specifier "%%" can be used to print out a single character '%'. This conversion specifier is used in the following statement in Program 2.5.

```
printf("We sell lemonade the by the cup, $1.29 per cup with 8.25% sales tax.\n");
```

The user then enters the number of cups of the lemonade to be purchased. Next, the value is assigned to the variable `cups` by the function `scanf()`.

Processing: First, the subtotal cost is calculated by multiplying the number of cups with the price 1.29. The sales tax is then calculated as 8.25% of the subtotal. Next, these two costs are added together as the total cost of the transaction.

2.4. Debugging Programs in ChIDE

Termination: Finally, all these break-down costs are displayed as the output. An interactive execution of Program 2.5 is shown below:

```
Welcome to Mary's Lemonade Shop
We sell lemonade by the cup, $1.29 per cup with 8.25% sales tax.
Please enter the number of cups.
3
Subtotal: $3.87
    Tax: $0.32
Total: $4.19
Thank you.
```

In this execution, the value 3 for the number of cups of lemonade is entered at the prompt.

Program 2.5 can be extended to handle a purchase order when the Lemonade Shop offers a discount for the sale of lemonade, as described in an exercise for this chapter.

2.3.1 Copying Contents in a Program to Create a New Program in ChIDE

Unlike a calculator, an existing Ch program can be copied to a new file. This newly created file can be modified to become a new program. This process of creating a new program can save a lot of typing. There are many different ways to copy programs (namely files). In ChIDE, we can copy the contents of a program to create a new program conveniently. Below are the step-by-step instructions for copying the contents of a program to create a new program in ChIDE. It copies the file `lemonade2.ch` in Program 2.5 to a new program `yogurt.ch`.

Copying the Program `lemonade2.ch` to Create a New Program `yogurt.ch`

1. Open the file `lemonade2.ch` in Program 2.5 in the folder `C:\C-STEM\LearnCh` for Windows, `/opt/C-STEM` for Mac OS X, `/usr/local/C-STEM` for Linux in the file broswer pane as shown in Figure 1.6.
2. Select all the contents of this program by clicking the command `Edit->Select All` or holding the left button of the mouse and dragging the mouse to select the contents to be copied.
3. Click the right button to bring up the menu and click the `Copy` command on the menu to copy the selected contents into the buffer. Or use `Ctrl+C` for a shortcut for copying.
4. Open a new document by clicking the first icon on the toolbar that looks like a little piece of paper with a folded corner, as shown in Figure 1.2.
5. Move the cursor to the editing page, click the right button to bring up the menu, and click the `Paste` command on the menu to paste the contents in the buffer to the opened document. Or use `Ctrl+V` for a shortcut for pasting.
6. Save this document as a new program `yogurt.ch`. You can then solve the problem using the program `yogurt.ch` as described in Exercise 8 on page 32.

(E) Do Exercises 8 and 9 on page 32.

2.4 Debugging Programs in ChIDE

Prerequisite: Understanding variable types and program structure

2.4. Debugging Programs in ChIDE

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.3, D1.4, D2.1, D2.2, D4.1

Objective: Demonstrate how to use debugging tools to find and fix errors in a computer program.

Nobody can write a perfect article, especially a lengthy one, without going through many rounds of editing. Similarly, nobody can write perfect code on the first try, especially for a complicated program. A large part of programming is finding and fixing errors. The process of fixing errors will stimulate your brain. You will also learn critical thinking and reasoning. In addition, executing a program line-by-line in the debug mode described in this section will help you understand how programs are executed.

There are two kinds of errors in a program: syntax error and runtime error. A **syntax error** refers to an error in the syntax of code. A **syntax error** can be detected by a compiler or interpreter, when the code is processed, as shown in Figure 1.4. Multiple error messages may be generated for one syntax error. In this case, the first error message is the most relevant to fixing the error. A syntax error in a program is relatively easy to fix after you have learned a programming language.

A **runtime error** occurs during the execution of a program. For example, dividing an integer by zero is a runtime error. Runtime errors are harder to find than syntax errors because they only occur under certain conditions. For example, when a runtime error occurs, your Web browser or computer might be frozen.

Another error is the **algorithmic error** or **logic error**, which cannot be detected by a compiler or interpreter. For example, you might, by mistake, have typed in a wrong value or formula in an equation for calculation. As a result, the output from the program execution is incorrect or is not what you would expect. If a program has either a runtime or logic error, the program has a **bug**. The process of finding and fixing bugs is called **debugging**. Debugging, especially for a large program, is more difficult than fixing syntax errors. It requires patience and experience. Sometimes it takes a long time to fix a bug.

A **debugger** is a tool for debugging programs. To fix a bug in a small program, you can step through the program line-by-line using a debugger. At each step, you can examine the values of all variables and expressions, or even change values of variables. To fix a bug in a large program, you need to isolate the problem by setting breakpoints. Once the program execution hits a breakpoint, you can examine and change the values of variables at that point and execute the program line-by-line.

ChIDE can be used not only to edit and execute programs, but also as a debugger. As described in section 1.2.2 in Chapter 1, ChIDE has four panes: the editing pane, debug pane, debug command pane, and input/output pane, as shown in Figure 2.4. The menus labeled Start to Clear on the **debug bar** in Figure 2.4 are **debug commands**.

2.4.1 Executing Programs in Debug Mode

The user can execute the program line-by-line either using the command Step or Next. For simple statements, the command Step is the same as Next. However, they are different when a function call is executed, which will be described in section 7.2 in Chapter 7. During debugging, the command Continue can be invoked to continue the execution of the program until it hits a breakpoint or until the program ends.

The program may not be edited when it is being executed and debugged. Otherwise, the message

Warning: Any changes made to the file during debugging will not be reflected in the current debugging session.}

will be displayed in a popup window. However, when a program has finished its execution, it can be edited.

2.4. Debugging Programs in ChIDE

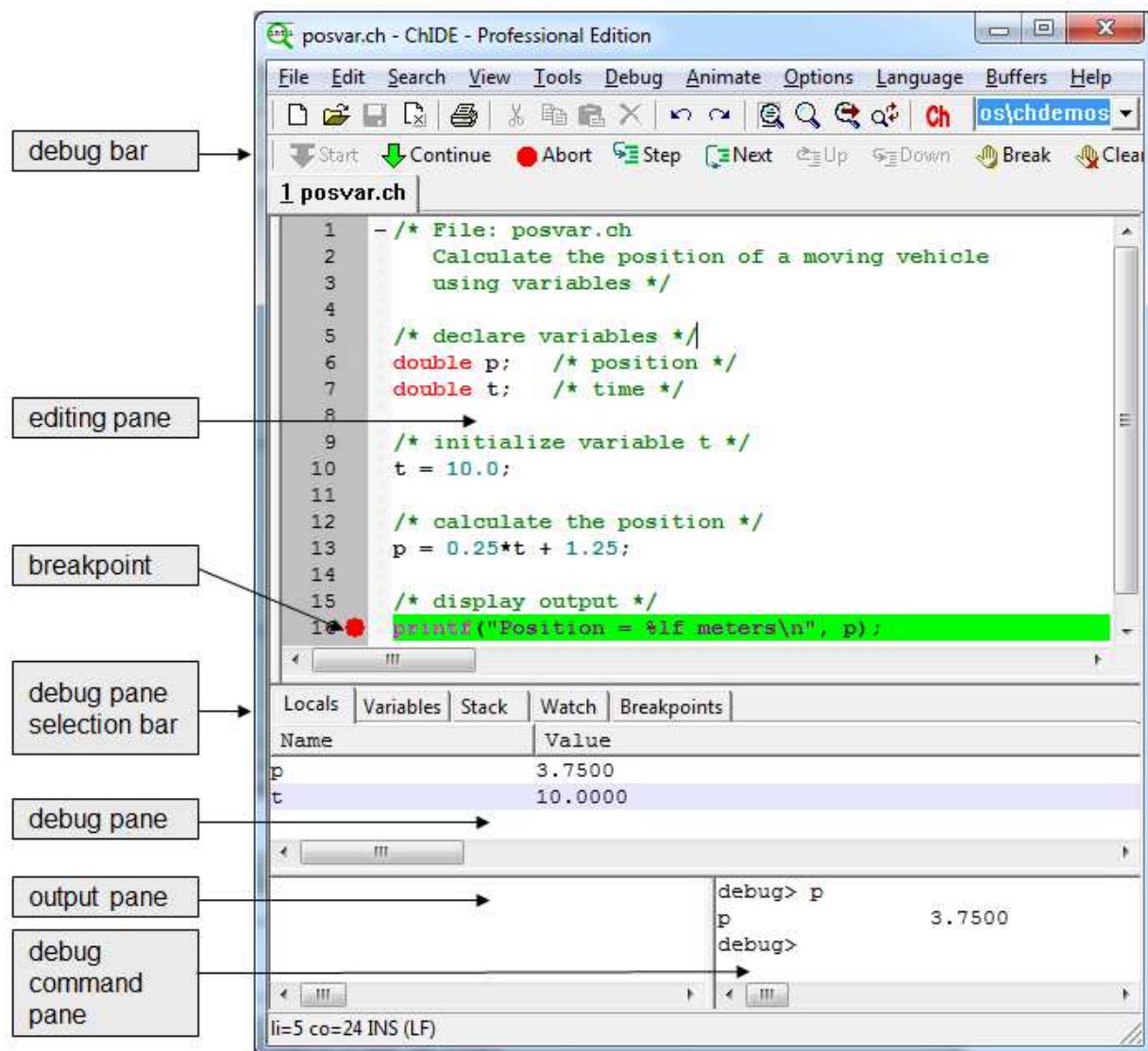


Figure 2.4: Debugging `posvar.ch` in Program 2.1 showing values for all variables in the program in ChIDE.

2.4. Debugging Programs in ChIDE

If the program execution has failed and is taking too long to complete, then the command `Abort` can be used to stop the program.

You should now open the program `posvar.ch` in Program 2.1 in ChIDE. While you read the next sections, you can then run it in debug mode.

2.4.2 Monitoring Local Variables and Their Values in the Debug Pane

When a program is executed line-by-line by the commands `Step` or `Next`, the values of variables in the current stack can be examined in the debug pane by clicking the menu `Locals` on the debug pane selection bar. When control of the program execution is inside a function, the command `Locals` displays the values of local variables and arguments of the function. When control of the program execution is not in a function of a Ch script, command `Variables` displays the values of global variables of the program. Functions and global variables will be described in Chapters 7. As shown in Figure 2.4, when program `posvar.ch`, is executed at the highlighted line 16 (displayed in the green color on the screen), local variables `p` and `t`, and their values 3.7500 and 8.0000, respectively, are displayed in the debug pane.

2.4.3 Changing Values of Variables in the Debug Command Pane

Many debug commands in the debug command pane are available during the debugging of a program. A prompt

```
debug>
```

inside the debug command pane indicates that the debugger is ready to accept debug commands. Type the command `help`, and it will display all available commands. Details using the debug features in ChIDE can be found online by clicking `Help` on the menu bar.

One of the most important features of debug commands in the debug command pane is to obtain and modify values for variables of the debugged program at runtime. One can also just type an expression as a debug command. The expression will be displayed on the left, and its value displayed on the right.

Example When program `posvar.ch` is stopped at line 16, as shown in Figure 2.4, the debug command pane will be able to accept debug commands and expressions. You can obtain the values of expressions using the variables `p` and `t`. You can also change the values of these variables. The interactive session inside the debug command pane is shown below.

```
debug> p
p           3.7500 // the original value 3.75 for p

debug> 2*p
2*p         7.5000 // the expression 2*p

debug> p = 30.0          // p is changed to 30
p = 30.0      30.0000
debug> p
p           30.0000 // its new value displayed
```

In these debug commands, the original value 3.75 for the variable `p` is displayed first. The expression `2*p` is evaluated. Then, `p` is changed to 30. Finally, its new value is displayed. At this point, if the program execution is continued by one of the commands `Continue`, `Step`, or `Next` on the debug

2.5. Chapter Summary

bar, the variable `p` has the value 30.

 Do Exercise 10 on page 33.

2.5 Chapter Summary

2.5.1 Programming Tips

Good Programming Practice

1. Separate the declaration statements from the executable statements with a blank line.
2. Use meaningful variable names for self-documentation and readability. For example,

```
double position, speed;
```

3. To make the code more readable, use lowercase letters for a simple variable name. For a variable name with multiple words, use capital letter for the second and/or third words. For example,

```
double posTrain, posSportsCar, posSportsCar2;
```

4. Display a prompt first using the function `printf()` when the program is requesting data from the user using the function `scanf()`. For example,

```
printf("Please input a number\n");
scanf("%d", &n);
```

Common Programming Errors

1. Variable names beginning with a capital letter or with all capital letters. For example,

```
double Position, SPEED;           // bad
double position, speed;          // good
```

2. Missing the semi-colon at the end of a statement. For example,

```
a = b + c                      // bad
a = b + c;                     // good
```

3. Forget the symbol `%` in a conversion specification in the format control string in the function `printf()` or `scanf()`.

4. Use the conversion specifier `"%lf"`, instead of `"%d"`, to output from or input into a variable `int` type. For example,

```
int n;
printf("n = %lf\n", n);
scanf("%lf", &n);                // bad
scanf("%d", &n);                // good
```

2.5. Chapter Summary

5. Use the conversion specifier "%d", instead of "%lf", to output from or input into a variable **double** type. For example,

```
double x;
printf("x = %d\n", n);
scanf("%d", &x);           // bad
scanf("%lf", &x);         // good
```

6. Forget to precede a variable with an ampersand for the function **scanf()**. For example,

```
int num;
scanf("%d", num);          // bad
scanf("%d", &num);         // good
```

7. Add an extra "\n" in the format string for the function **scanf()**. For example,

```
int num;
scanf("%d\n", &num);       // bad
scanf("%d", &num);         // good
```

2.5.2 Terminology

General Concepts

algorithmic error		
debugging	constant	debugger
escape characters	declaration	editing pane
keywords	field width	floating-point numbers
operators	identifiers	initialization
punctuators	precision	logic error
syntax error	runtime error	processing
	termination	string

Ch Reserved Words

\\"		\\"
\a	\n	
int	double	scanf()
string_t		

ChIDE Related Concepts

breakpoint	debug bar	debug command pane
debug commands	Debug Commands->Abort	Debug Commands>Break
Debug Commands->Clear	Debug Commands->Continue	Debug Commands->Next
Debug Commands->Start	Debug Commands->Step	Debug Console Window
Debug Pane->Breakpoints	Debug Pane->Locals	debug pane selection bar

2.6. Exercises

2.6 Exercises

1. Some poor choices for program identifiers are shown below. What makes them poor choices?
 (a) double (b) 1zero (c) 0zero (d) ABC (e) abc#input (f) abc,def
2. State whether the following statement is true or false. If false, explain why.
 All variables in C must be declared before they are used.
3. One mile equals 1.609 kilometers. Write a program `mile2kmeter.ch` to convert 8 miles into kilometers. Display the result on the screen. The math formula for converting miles to kilometers is as follows:

```
kilometer = 1.609 * mile
```

4. A video rental shop charges \$3.99 for renting a movie. Write a program `rental.ch` to calculate the cost for renting three movies. The math formulas for calculating the cost for movie rentals are as follows:

```
num = 3
price = 3.99
cost = num*price
```

5. Find the error(s) in each of the following program segments. Explain how each error can be corrected.

- (a)

```
string_t name;
scanf("%s", name);
```
 - (b)

```
double x;
scanf("%d", &x);
printf("%d", x);
```
 - (c)

```
int n;
scanf("%lf", &d);
printf("%lf", d);
```
6. One mile equals 1.609 kilometers. Write a program `mile2kmeter2.ch` to take the user input distance in miles and convert it to kilometers. The program accepts the user input for miles from the keyboard and displays the result on the screen. Check your program with the value 38 miles.
 7. Write a program `inspire.ch` to inspire your fellow students to be successful in their future career. When the program is executed, it shall have the following conversation. The contents inside a pair of bracket [] are from the user at the prompt. The contents inside a pair of braces { } are replacement of the input from the user.

```
What is your name?
[John]
Hello {John},
I enjoy computing, what type of hobbies do you like?
[Robotics]
{Robotics} sounds really fun.
What would you like to do in the future?
[scientist]
You should definitely try and be a {scientist}.
Good Luck!
```

8. Write a program `yogurt.ch` for a Yogurt Shop to process the sale of frozen yogurt. The price for frozen yogurt is \$0.39 per ounce. The sales tax is 8.25 percent. The math formulas for calculating the cost for frozen yogurt are as follows:

```
subtotal = 0.39*weight
tax = 0.0825*subtotal
total = subtotal+tax
```

2.6. Exercises

9. Write a program `icecream.ch` for an Ice Cream Shop to process the sale of ice cream. The price for ice cream is \$0.47 per ounce. Compute the cost and apply a 10% discount. The sales tax is 8.5 percent of the adjusted subtotal cost. The math formulas for calculating the total cost for ice cream are as follows:

```
subtotal = 0.47*weight
discount = 0.1*subtotal
adjustedSubtotal = subtotal-discount
tax = 0.085*adjustedSubtotal
total = adjustedSubtotal+tax
```

10. A company pays its employees at the rate of \$25 per hour worked and withholds 30% of the gross pay for federal and state income tax. Write a program `payment.ch` to calculate the gross pay, deducted tax, and net pay of an employee based on the hours worked as the user input. The math formulas for calculating the payment are as follows:

```
grosspay = 25*hours
tax = 0.3*grosspay
netpay = grosspay-tax
```

Execute the program in debug mode.

CHAPTER 3

Operators and Expressions

C is commonly used for solving applied problems with numerical computation. A numerical expression may consist of many operations. In C, an *operator* is a symbol or group of symbols that can be used for calculations. For example, + and * are familiar operators representing addition and multiplication. The variables and numbers used with the operator are called *operands*. For example, in the expression `i+2`, `i` and `2` are the operands and `+` is the addition operator. In this chapter, some concepts related to operators and expressions are introduced first. More operators are then described in the subsequent sections.

3.1 Expressions

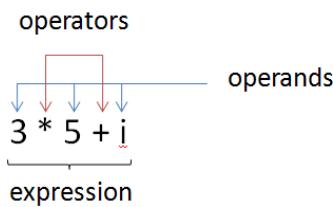
An *expression* consists of a valid sequence of operators and operands that specifies how to compute a value. Some valid expressions in C are listed in Table 3.1. An *integral expression* produces a result in an integer type. For example, the expression `(3 * 5 + i)` with `i` declared as `int` type is an integral expression. Operators and operands in the expression `3 * 5 + i` are shown in Figure 3.1.

A *floating-point expression* produces a result in a floating-point type. For example, `3.3 + 4.5` is a floating-point expression of `double` type. A *constant expression* contains only constant values.

Table 3.1: Types of expressions.

Expression Type	Example
integral expression	<code>3 * 5 + i</code>
floating point expression	<code>3.3 * 4.5</code>
constant expression	<code>3 * 5 + 2</code>

3.2. Assignment Operator

Figure 3.1: Operators and operands in the expression $3 * 5 + i$.

3.2 Assignment Operator

Prerequisite: Understanding variable types and program structure

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D4.1

Objective: Develop computer code to declare and assign values to variables in a C program.

Sometimes it is useful to change the value of a variable after it has been initialized. For this, we use the assignment operator '='.

When a floating-point number is assigned to an integer variable, the fractional part will be discarded as shown below.

```
> int i
> double d = 10.123    // d is 10.123
> i = d                // i becomes 10
10
> i = 10.789           // i becomes 10
10
```

3.3 Arithmetic Operators

Prerequisite: Understanding variable types and program structure

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D4.1

Objective: Develop computer code to apply arithmetic operators to accomplish addition, subtraction, multiplication, division, and modulus operations in a Ch program.

3.3. Arithmetic Operators

Table 3.2: Arithmetic operations.

operator	operation	description
-	$-x$	negation
+	$x + y$	addition
-	$x - y$	subtraction
*	$x * y$	multiplication
/	x / y	division
%	$i \% j$	modulus

Arithmetic operations involve negation (making negative), addition, subtraction, multiplication, and division as shown in Table 3.2. For the negation operation (-), the data type of the result is the same as the data type of the operand. The sign of a number changes with the use of the negation operator. the addition (+), subtraction (-), multiplication (*), and division (/) operations work as you would expect them to.

 Note that even for multiplication of a variable with a constant such as `5*i`, the multiplication operator '*' is still needed. In addition, subtraction, multiplication, and division operations, if both operands are integer, the result is an integer. If one of operands is decimal, the result is a decimal. When dividing two integers, the remainder is dropped, which results in a possible loss of data. Unless the result of a division operation is a whole number, to get the correct numerical result, one of the numbers must be a decimal.

Examples of arithmetic operations are shown below.

```
> int i = 10, j=5
> 5*i+2           // all integers
52
> 8 - 3.5         // integer and decimal, result is decimal
4.5000
> 2*3
6
< 19/5            // remainder 4 of 19/5 is lost
3
> 19.0/5          // numerator is a decimal
3.800
> 19/5.0          // denominator is a decimal
3.800
> j/i             // 5/10 becomes 0
0
```

The '%' is known as the **modulus operator** and returns the remainder of a division operation. For the expression `i%j`, the remainder is zero when `i` can be divided by `j` exactly. An example of the modular operation is shown below.

```
< 19/5            // remainder 4 of 19/5 is lost
3
> 19%5            // get remainder 4 of 19/5
4
```

This result is found from dividing 19 by 5, which gives you 3, with a remainder of 4. The modulus operator (%) will display the remainder of 4. Additional examples are given in the table below.

3.3. Arithmetic Operators

expression	result
$0 \% 3$	0
$1 \% 3$	1
$2 \% 3$	2
$3 \% 3$	0
$4 \% 3$	1
$5 \% 3$	2
$6 \% 3$	0

The modulus operation can be used to find if an integer is odd or even number, which is useful for many applications. An even number is a multiple of two. Any multiple of two leaves a remainder of zero when divided by 2. Therefore, if n is an odd number, the remainder of the integer divided by 2, $n \% 2$, is 1. Otherwise, $n \% 2$ is 0.

The modulus operator (%) can only be used with integer operands. All other operators can be applied to operands of arithmetic type which consists of integer and floating-point types.

 Do Exercises 1, 2, and 3 on page 43.

Application: Calculating the Average of Three Numbers

Problem Statement:

Write a program `average.ch` to calculate the average of three numbers input from the user.

The program `average.ch` in Program 3.1 illustrates the usage of the arithmetic operations. It calculates the average of three numbers stored in the variables `num1`, `num2`, and `num3` entered by the user by the statement.

```
average = (num1+num2+num3) / 3;
```

3.4. Precedence and Associativity of Operators

```

/* File: average.ch
   Calculate the average of three numbers */

/* declare variables */
double num1, num2, num3,      /* three numbers */
       average;                /* average */

/* enter the user input */
printf("Welcome to the Average Calculator\n");
printf("Please enter a number\n");
scanf("%lf", &num1);
printf("Please enter another number\n");
scanf("%lf", &num2);
printf("Please enter one more number\n");
scanf("%lf", &num3);

/* calculate the average */
average = (num1+num2+num3)/3;

/* display output */
printf("The average is %lf\n", average);

```

Program 3.1: Calculating the average of three numbers.

An interactive execution of Program 3.1 to calculate the average of three numbers 12, 14.5, and 10.1 is shown below:

```

Welcome to the Average Calculator
Please enter a number
12
Please enter another number
14.5
Please enter one more number
10.1
The average is 12.200000

```

 Do Exercises 4 and 5 on page 43.

3.4 Precedence and Associativity of Operators

Prerequisite: Understanding variable types, program structure, and arithmetic operators

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D4.1

Objective: Understand the order of operations as it pertains to mathematical operators.

Assignment operator and arithmetic operators are summarized in Table 3.3. C uses an *order of operations*.

3.4. Precedence and Associativity of Operators

Table 3.3: Precedence and associativity of arithmetic, negation, and assignment operators

Operators	Associativity
- (negation)	right to left
* / %	left to right
+ -	left to right
=	right to left

ations similar to what we use in math. The **order** is referred to as **precedence** and it determines which operation will be executed first in an expression. For the familiar math operators like '+', '-·', '*'·, and '/' the precedence is identical to the order of operations in math. For example, in the expression $2+3*4$, $3*4$ will be performed first to get 12 and then 2 will be added to get 14. This is because '*' has a higher precedence than '+'. Parenthesis fill the same roll in C as in math, therefore an expression inside parenthesis is always performed before the ones outside of them. C has many other operators besides these. Table 3.3 lists the commonly used operators in order of precedence. An operator at the higher level has higher precedence than operators at the lower level. Operators at the same level have the same precedence.

When two operators have the same precedence, like '+' and '-·', C has a second way, called **associativity**, to determine which should be performed first. Table 3.3 lists the associativity of the operators in C. In the case of '+' and '-' associativity reads the operators from left to right. For example, in the expression $7-2+6$, $7-2$ is done first to get 5 because of the first operator on the left. Then $5+6$ is added to get 11. Most operators are left to right associative like in this example.

Complicated Expressions

For complicated expressions parentheses '()' are used to tell the computer which operations to perform first. They can also be used to make an expression more readable. For example, for the expression $2 + 3 * (4 + 1)$, the addition operation inside the parenthesis $(4 + 1)$ will be evaluated first with the result of $2 + 3 * 5$. Then, the multiplication $3 * 5$ will be carried out since the multiplication operation has higher precedence than the addition operation. Finally, the addition $2 + 15$ with the result 17 will be performed. The result can be verified in a Ch Command Shell as shown below.

```
> 2+3*(4+1)
17
```

As another example, the math formula

$$y = \frac{5-x}{2} + 2x - 4$$

can be programmed in C as follows.

```
y = (5-x)/2+2*x-4;
```

We need to put $(5 - x)$ into parentheses so that C recognizes that the whole expression $5-x$ is divided by 2. Without the parentheses, C will read $5-x/2$ as only x being divided by 2.

We could also write the expression as

```
y = (5-x)/2+(2*x)-4;
```

with the extra parentheses around $2*x$ to make it very clear that 2 will multiply by x before it is added. Note: In complicated expressions like $2*(1/2+(3.0-5))$ it is very easy to overlook division operations that will yield an incorrect result. In this example, $1/2$ will be calculated as 0 instead of 0.5.

 Do Exercises 6, 7, and 8 on page 44.

3.4. Precedence and Associativity of Operators

Use the Macro `M_PI` for π

A **macro** is a symbol or name that represents a predefined value. The macro **`M_PI`** for π is pre-defined in Ch.

Application: Calculating the Area of a Circle

Program 3.2 calculates the area of a circle as shown in Figure 3.2. The radius r of a circle in meters is entered by the user.

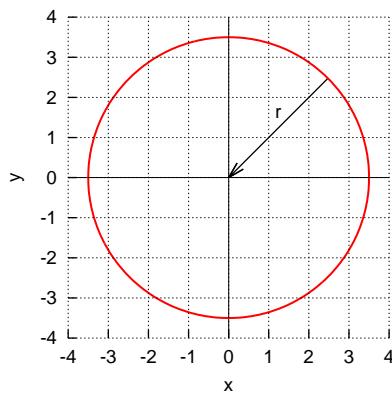


Figure 3.2: A circle with the radius r .

```
/* File: circle.ch
   Calculate the area of a circle */
/* declare variables */
double r, area;

printf("Enter the radius of a circle in meters:\n");
scanf("%lf", &r);

/* calculate the area */
area = M_PI*r*r;

/* display the result */
printf("The area of the circle is %lf square meters\n", area);
```

Program 3.2: Calculating the area of a circle.

In Program 3.2, the macro **`M_PI`** for π is used. An interactive execution of Program 3.2 is shown below:

```
Enter the radius of a circle in meters:
3.5
The area of the circle is 38.484510 m^2
```

Do Exercise 9 on page 44.

3.5. Exponential Expressions and Square Root

3.5 Exponential Expressions and Square Root

Prerequisite: Understanding variable types, program structure, and arithmetic operators

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D4.1

Objective: Use predefined functions to compute exponential or square root values.

There is no exponential operator in C. The mathematical function **pow**(*x*, *y*) with two arguments can be used to calculate the exponential expression x^y . For example, the exponential expression 10^3 can be evaluated by

```
> pow(10, 3)
1000.0000
```

Note that the result of the function **pow()** is a decimal even if its arguments are all integer values. Multiplications take less time for C to process than the function **pow()**. Therefore, multiplications are usually used to evaluate an exponential expression when the exponent in the exponential expression is a small value, such as x^2 or x^3 . This is important for computer programs that take a long time to finish.

The commonly used math expression \sqrt{x} for the square root of *x* can be calculated by the math function **sqrt**(*x*). This math function takes one argument *x* and returns a value of **double** type for the square root of *x*. For example,

```
> sqrt(2)
1.4142
> sqrt(3.0)
1.7321
```

Application: Calculating the Length of a Right Triangle

Problem Statement:

For the right triangle shown in Figure 3.3, *c* is the length of the hypotenuse. *a* and *b* are the lengths of the two legs. Based on the Pythagorean theorem, they are related by the formula

$$c^2 = a^2 + b^2 \quad (3.1)$$

If the lengths of two legs are 3 and 5 meters, calculate the length of the hypotenuse.

3.6. Chapter Summary

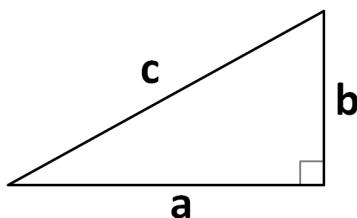


Figure 3.3: A right triangle with the length c for the hypotenuse, and a and b for the other two legs.

Given the lengths of two legs, the length of the hypotenuse for a right triangle can be calculated by the formula

$$c = \sqrt{a^2 + b^2} \quad (3.2)$$

We can find the value for c when a is 3 meters and b is 5 meters interactively in a Ch Command Shell as follows.

```
> sqrt(3*3 + 5*5)
5.8310
```

The length of the hypotenuse is 5.831 meters.

```
/* File: hypot.ch
   Calculating the length of the hypotenuse for a right triangle. */

/* declare variables for the lengths of triangles */
double a = 3.0, b = 5.0, c;

/* calculate the hypotenuse */
c = sqrt(a*a+b*b); // c = sqrt(pow(a, 2)+ pow(b, 2))

/* display the hypotenuse */
printf("The hypotenuse = %lf meters\n", c);
```

Program 3.3: Calculating the length of the hypotenuse for a right triangle.

We can also write a program `hypot.ch` as shown in Program 3.3 to solve this program. The output of the program 3.3 is as follows.

```
The hypotenuse = 5.830952 meters
```

Do Exercises 10, 11, 12, 13, and 14 on page 44.

3.6 Chapter Summary

3.6.1 Programming Tips

Good Programming Practice

1. Place one space on both side of a binary operator. For example,

3.7. Exercises

```
a = b + c;
```

Common Programming Errors

- Divide two integers. For example, $3/2$ is 1, instead of $3.0/2$ with 1.5.

3.6.2 Terminology**General Concepts**

π	arithmetic operators	assignment operator
modular operator	negation operator	macro
operators	operator associativity	operand
precedence		operator precedence

Ch Reserved Words

+ sign	+ addition operator	= assignment operator
/ division operator	% modulus operator	* multiplication operator
- sign	- subtraction operator	M_PI
pow()	sqrt()	

3.7 Exercises

- Calculate the values of the following expressions at $x = 2.5$ in a Ch Command Shell.
 - $2x - 4$
 - $2(x - 4)$
 - $4/3$
 - $(4/3)3.14x^2 - 5$
 - $x^2 + 5x - 6$
- The temperature c in Celsius and the temperature f in Fahrenheit are related by the formula:

$$f = \frac{9c}{5} + 32$$

Correct the error below for converting temperature 42 degrees in Celsius to degrees in Fahrenheit.

```
printf("42 degrees in Celsius is %lf degrees in Fahrenheit\n",
      9*42/5+32);
```

- The formula for the volume of a sphere is $\frac{4}{3}\pi r^3$, where r is the radius of the sphere. Correct the error below for calculating the volume of a sphere with a radius of 5 meters.

```
printf("volume of a sphere with a radius 5 m is %lf cubic meters\n",
      4/3*3.1415926*5*5*5);
```

- Modify the program `average.ch` in Program 3.1 as a program `average2.ch` to calculate the average of three numbers from the user input. The modified program calls the function `scanf()` only once with three conversion specifiers.
- A Picture Frames Shop charges \$3.75 per meter for a frame, \$8.35 per square meter for glass, and \$16 per hour for labor. The sales tax is 8.5 percent on the total. The math formulas for calculating the cost of the transaction are as follows:

3.7. Exercises

```

perimeter = 2*(width + height)
area = width*height
subtotal = 3.75*perimeter + 8.35*area + 16*hours
tax = 0.085*subtotal
total = subtotal + tax

```

Write a program `frame.ch` to calculate the cost of each frame they build. The program accepts the user input for the width and height of a frame, and the hours worked. It prints the total, tax, and grand total on the screen.

6. For the following expressions in C, write their corresponding mathematical expressions. You may add proper parentheses to avoid any confusion,

$$(a) (4/3.0)*3.14*r*r*r \quad (b) 4.0/3*3.14*r*r*r \\ (c) (9.0/5.0)*c + 32 \quad (d) 9.0/5.0*c + 32$$

7. Calculate the values of the following expressions at $x = 2.5$ in a Ch Command Shell.

$$(a) 3 + 2(x + 4) \quad (b) \frac{x+4}{x^2+5} \quad (c) \frac{x+4}{(x+5)^2} \quad (d) 9 + 5\frac{x+4}{x^3+5}$$

8. For the following mathematical expressions, calculate their values in a Ch Command Shells for $x = 2.5$, $y = 3.5$, and $r = 4.5$. You may add proper parentheses to avoid any confusion.

$$(a) \frac{x+4}{y+5} \quad (b) 9 + 5\frac{x+4}{y+5} \quad (c) \frac{4}{3}3.14r^3$$

9. The radii for the inner and outer circles of a washer are $r_1 = 1.5$ and $r_2 = 2.5$ centimeters, respectively. Write a program `facearea.ch` to compute the face area of a washer using the formula $area = \pi r_2^2 - \pi r_1^2$.

10. For the right triangle shown in Figure 3.3, solve problems below in a Ch Command Shell.

- (a) Given $a = 2$ and $b = 4$, find c .
- (b) Given $b = 4$ and $c = 10$, find a .
- (c) Given $a = 4$ and $b = 10$, find c .

11. The formula for calculating the surface area of a sphere is $area = 4\pi r^2$, where r is the radius of the sphere. If the area of a sphere is 25 m^2 , write a program `spherearea.ch` to calculate the radius of the sphere using the formula $r = \sqrt{\frac{area}{4\pi}}$.

12. The mathematical formula for the total amount of the money invested with the interest compounded annually is

$$y = p(1 + r)^n$$

where y is the total amount, p the principal invested, r the interest rate, and n the number of years. The math function `pow(x, y)` can be used to calculate x^y . Write a program `interest.ch` to calculate the total amount of the money after 30 years for the invested principal of \$10,000 with 8 percent interest rate.

13. Given the lengths a, b, c of the three sides of a triangle, the area of the triangle can be calculated by the formula

$$area = \sqrt{s(s - a)(s - b)(s - c)}$$

where s is the semiperimeter (half the perimeter) of the triangle defined as

$$s = \frac{a + b + c}{2}.$$

Write a program to calculate the area of a triangle with the lengths a, b , and c given as follows.

- (a) Program `trianglearea1.ch`: $a = 2\text{cm}, b = 3\text{cm}, c = 4\text{cm}$.
 - (b) Program `trianglearea2.ch`: $a = 3\text{m}, b = 4\text{m}, c = 5\text{m}$.
14. ¶ The straight-line distance of two points (x_1, y_1) and (x_2, y_2) in a Cartesian plane can be calculated by the formula

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

3.7. Exercises

- (a) Write a program `distance1.ch` to calculate the distance for two points (2, 3) and (4, 5) in a plane.
- (b) Write a program `distance2.ch` to calculate the distance for two points (4, 3) and (6, 5) in a plane.
- (c) Write a program `distance3.ch` to calculate the distance for two points (1, 3) and (4, 2) in a plane.

CHAPTER 4

Graphical Visualization

As the saying goes, *a picture is worth a thousand words*. Graphical plotting is useful for visualization and understanding many problems in math, science, and engineering. In this chapter, we will learn how to write programs for graphical plotting and their applications. Chapters 7 and 8 will introduce some additional features for graphical plotting.

4.1 Plotting Points for Scatter Plots and Trend Lines

A **scatter plot** is a graph with points to show a possible relationship between two sets of data. It can be used effectively to show some trends. Table 4.1 contains the data for the temperature relationship between Fahrenheit and Celsius. The program `points.ch` listed in Program 4.1 plots these five data points on a scatter plot, as shown in Figure 4.1. The graph reveals that the temperature relationship between Fahrenheit and Celsius is linear.

As seen in Program 4.1, a program generating a plot typically contains the following statements.

```
#include <chplot.h>
CPlot plot;
plot.title("title");
plot.label(PLOT_AXIS_X, " xlabel");
plot.label(PLOT_AXIS_Y, " ylabel");
/* add plotting data here */
plot.plotting();
```

A line that starts with a `#` has a special meaning, which depends on the symbol following it. The line

```
#include <chplot.h>
```

Table 4.1: Data for temperature relationship between Fahrenheit and Celsius.

Fahrenheit	-10	20	50	80	110
Celsius	-23.33	-6.67	10.00	26.67	43.33

4.1. Plotting Points for Scatter Plots and Trend Lines

```

/* File: points.ch
   Plot the temperature relationship between Fahrenheit and Celsius using five points*/
#include <chplot.h>           // for CPlot
CPlot plot;                   // declare the variable plot

plot.title("Temperature Relation");    // title of the plot
plot.label(PLOT_AXIS_X, "Fahrenheit"); // x-label of the plot
plot.label(PLOT_AXIS_Y, "Celsius");     // y label of the plot

/* add five data points for plotting */
plot.point(-10, -23.33);
plot.point(20, -6.67);
plot.point(50, 10.00);
plot.point(80, 26.67);
plot.point(110, 43.33);

plot.plotting();               // generate the plot

```

Program 4.1: Plotting data representing the temperature relationship between Fahrenheit and Celsius.

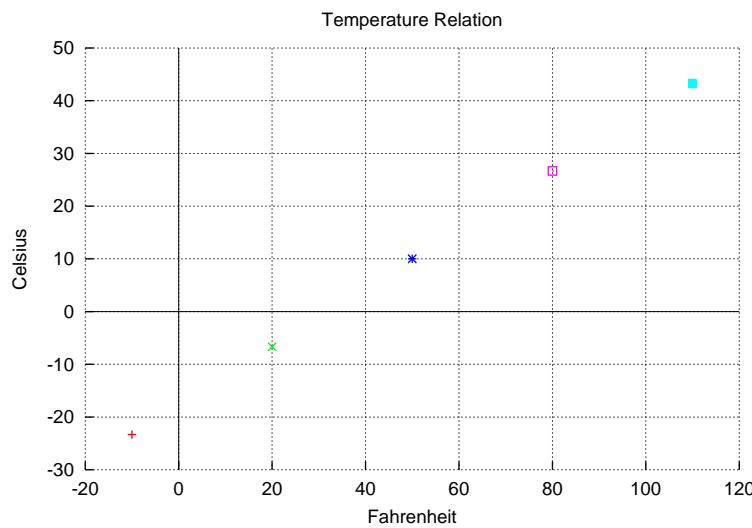


Figure 4.1: The temperature relationship between Fahrenheit and Celsius, generated by Program 4.1.

4.1. Plotting Points for Scatter Plots and Trend Lines

instructs Ch to include the header file **chplot.h** in the program. The contents made available via **#include** is called a **header** or **header file**. The purpose of including the header file **chplot.h** is to use the class **CPlot** defined in this header file. A class is a user defined data type in Ch. The symbol **CPlot** can be used in the same manner as the symbol **int** or **double** to declare variables. The line

```
CPlot plot;
```

declares the variable **plot** of type **CPlot** for plotting. A function associated with a class is called a **member function**. For example, the function **plot.title()** or **title()** is a member function of the class **CPlot**. In Program 4.1, member functions of the class **CPlot** are called to process the data for the object **plot**. The function call

```
plot.title("title");
```

adds a title to the plot. The argument for this member function is string. If this member function is not called, the generated plot will have no title.

The subsequent two function calls

```
plot.label(PLOT_AXIS_X, " xlabel");
plot.label(PLOT_AXIS_Y, " ylabel");
```

add labels to the x and y coordinates. The macros **PLOT_AXIS_X** and **PLOT_AXIS_Y** for the x and y axes, respectively, are defined in the header file **chplot.h**. The second arguments of the above two member functions are also strings for labels. If these two functions are not called, by default, the label for the x-axis will be “x” whereas the label for the y-axis will be “y”.

There are many member functions to add plotting data to the plotting object. One of them is to add a point to the plotting object. The member function call

```
plot.points(x, y);
```

draws a point at the coordinate (x, y) . In Program 4.1, five data points in Table 4.1 are added to the graph by the statements.

```
plot.point(-10, -23.33);
plot.point(20, -6.67);
plot.point(50, 10.00);
plot.point(80, 26.67);
plot.point(110, 43.33);
```

After the plotting data are added, finally, the program needs to call the function

```
plot.plotting();
```

to generate a plot,

The member functions of the plotting class **CPlot** used in this document are summarized and documented in Appendix A.

 Do Exercises 1(a) and 2(b) on page 66.

4.1.1 Copying and Printing Plots

Unlike in a graphing calculator, plots in Ch can be copied and pasted easily into other applications such as a Word file. In Windows, a displayed plot can be copied to the clipboard first, then pasted to other programs such as a Word document or PowerPoint to print out or for a project report. Clicking the first menu on the toolbar on the upper left corner of the plot, as shown in Figure 4.2, will copy the plot to the clipboard. The plot in the clipboard can then be pasted into other programs.

On Mac OS X, move the cursor on a plot first, press the two keys Command and c to copy the plot to the clipboard. Then, press the two keys Command and v to paste the plot to a Word file.

 Do Exercises 1(b) and 2(b) on page 66.

4.2. Plotting Lines Using Two Points

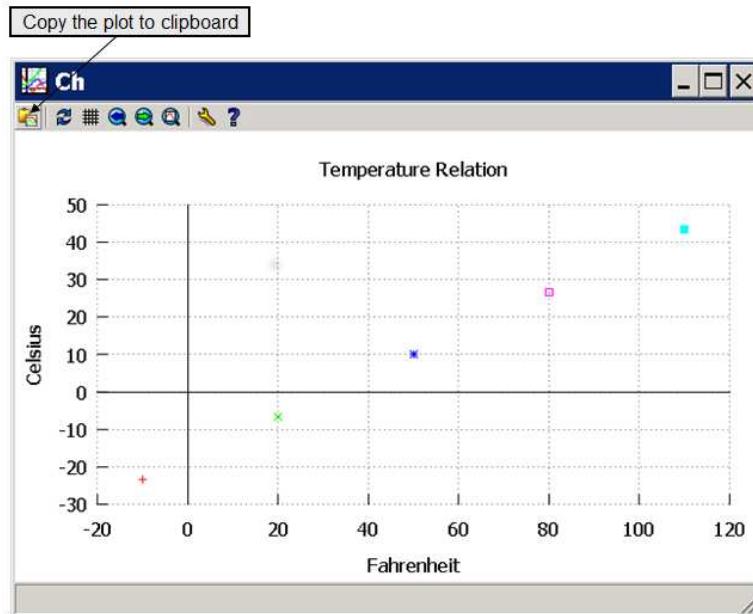


Figure 4.2: Copying the plot to clipboard.

4.2 Plotting Lines Using Two Points

Only two points are necessary to draw a straight line. The plotting member function

```
plot.line(x1, y1, x2, y2);
```

draws a straight line between the two points (x_1, y_1) and (x_2, y_2) .

Application: Plotting a Linear Relation

Problem Statement:

The temperature c Celsius is related to the temperature f Fahrenheit by the linear equation

$$c = 5(f - 32)/9 \quad (4.1)$$

Write a program `line.ch` to convert 20 degrees Fahrenheit to degrees Celsius, and plot the linear relation between the temperature c Celsius and the temperature f Fahrenheit expressed by equation (4.1).

Program 4.2 first converts 20 degrees Fahrenheit to degrees Celsius and displays the following output in the input/output pane.

```
20 degrees Fahrenheit is -6.67 degrees Celsius
```

It then displays the plot shown in Figure 4.3 on the screen.

4.2. Plotting Lines Using Two Points

```

/* File: line.ch
   Plot the temperature relationship between Fahrenheit and Celsius
   using the member function line() for x from -10 to 110. */
#include <chplot.h>      // for CPlot
/* Declare variables */
double x1, y1, x2, y2;
CPlot plot;

/* convert 20 degrees Fahrenheit to degrees Celsius */
x1 = 20;
y1 = 5*(x1-32)/9;
printf("20 degrees Fahrenheit is %.2lf degrees Celsius\n", y1);

plot.title("Temperature Relation");
plot.label(PLOT_AXIS_X, "Fahrenheit");
plot.label(PLOT_AXIS_Y, "Celsius");

/* add a line connecting (x1, y1) and (x2, y2) to the plot */
x1 = -10;
y1 = 5*(x1-32)/9;
x2 = 110;
y2 = 5*(x2-32)/9;
plot.line(x1, y1, x2, y2);
plot.plotting();

```

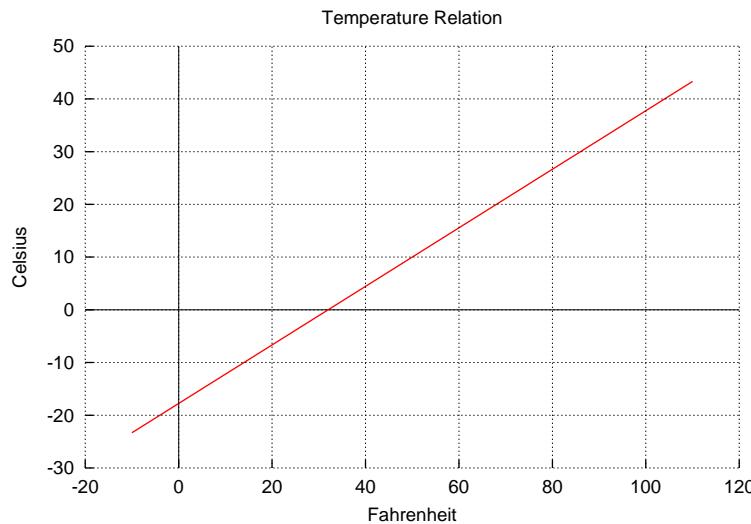
Program 4.2: Plotting the line $y = 5(x - 32)/9$ using two points.

Figure 4.3: The temperature relationship between Fahrenheit and Celsius, generated by Programs 4.2 and, 4.3, Program 7.5 in Chapter 7.

In Program 4.2, the y-coordinates y_1 and y_2 corresponding to x at $x_1 = -10$ and $x_2 = 110$, respectively, are calculated first. The two points (x_1, y_1) and (x_2, y_2) are then used to draw a straight line by the statement

```
plot.line(x1, y1, x2, y2);
```

4.3. Plotting Expressions

```
/* File: exprline.ch
   Plot the temperature relationship between Fahrenheit and Celsius
   using the member function expr() for x from -10 to 110. */
#include <chplot.h>
double x1, x2;
int num;
CPlot plot;

plot.title("Temperature Relation");
plot.label(PLOT_AXIS_X, "Fahrenheit");
plot.label(PLOT_AXIS_Y, "Celsius");

/* add a line with expression 5*(x-32)/9 for x from -10 to 110 with 100 points */
x1 = -10;
x2 = 110;
num = 100;
plot.expr(x1, x2, num, "5*(x-32)/9");
plot.plotting();
```

Program 4.3: Plotting the line $y = 5(x - 32)/9$ using a Ch expression and the member function **plot.expr()**.

 Do Exercises 3(a) and 4 on page 66.

4.3 Plotting Expressions

The relation represented in a mathematic expression can be plotted by using the member function **plot.expr()** in the plotting class **CPlot**

```
plot.expr(x0, xf, num, expx);
```

This member function will plot an expression defined as `expx` in term of the variable `x`. Adjacent points are connected by lines in the range `[x0, xf]` with the number of points specified by the argument `num`.

Program 4.3 uses the statement

```
plot.expr(x1, x2, num, "5*(x-32)/9");
```

to plot the expression $5(x - 32)/9$ from `x1` to `x2` with `100` points for `num`. It will display the same plot, shown in Figure 4.6.

The function can also be used to plot a complicated expression, such as a polynomial expression. For example, Program 4.4 uses the statement

```
plot.expr(x1, x2, num, "2*x*x-20*x+55");
```

to plot the polynomial $y = 2x^2 - 20x + 55$ for `x` from `x1=0` to `x2=10` with `100` points for `num`. The plot generated by Program 4.4 is shown in Figure 4.4.

4.4. Obtaining the Coordinates for Points on a Plot

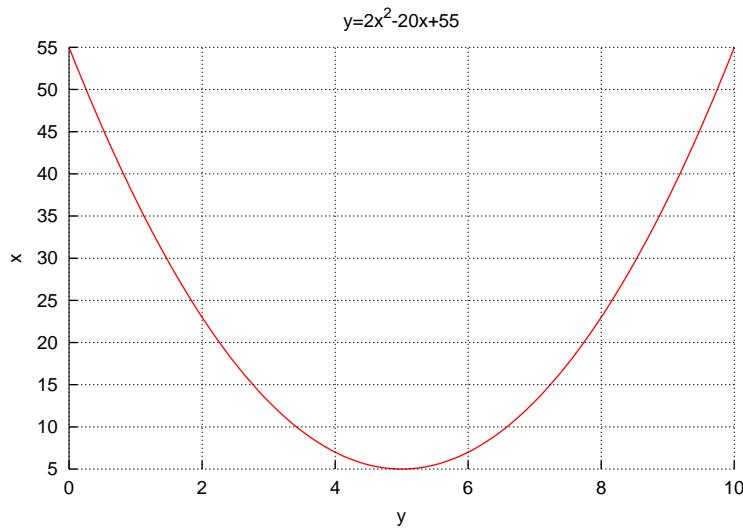
```

/* File: exprpoly.ch
   Plot the polynomial y = 2x^2-20x+55;
   using the member function expr() for x from 0 to 10. */
#include <chplot.h>
double x1, x2;
int num;
CPlot plot;

plot.title("y=2x^2-20x+55");
plot.label(PLOT_AXIS_X, "y");
plot.label(PLOT_AXIS_Y, "x");

x1 = 0;
x2 = 10;
num = 100;
plot.expr(x1, x2, num, "2*x*x-20*x+55");
plot.plotting();

```

Program 4.4: Plotting the polynomial $y = 2x^2 - 20x + 55$ using the member function **plot.expr()**.Figure 4.4: The polynomial $y = 2x^2 - 20x + 55$ generated by Programs 4.4.

Do Exercises 4(b) and 5(a) on page 67.

4.4 Obtaining the Coordinates for Points on a Plot

When you put the cursor on a displayed plot on the screen, the x and y coordinates for the point where the cursor points will appear on the lower left corner. Depending on the resolution of your screen setup, you may only be able to obtain an approximate value for a given point. For example, you can move the cursor to the y-intercept and x-intercept points, as shown in Figure 4.3, to obtain approximate values for these two intercepts. Note that the *y*-intercept is the *y* value where a graph intersects with the *y*-axis. The *x*-coordinate of the *y*-intercept is always 0. The *x*-intercept is the *x* value where a graph intersects with the *x*-axis. The *y*-coordinate of the *x*-intercept is always 0. The *x*-intercept in Figure 4.3 is 32. The *y*-intercept is 17.78.

4.5. Plotting Rectangles, Squares, and Circles

Note that the member function `plot.line()` draws a line with only two data points. We cannot zoom in on a point of the line to obtain accurate values of the x and y coordinates of the point. A line generated by the member function `plot.expr()` with many points can be zoomed in to obtain more accurate values for the coordinate of a point on the line. In sections 7.5.1 and 7.5.2 in Chapter 7, we also will learn how to plot a straight line with multiple points using the member function `plot.func2D()`. Then, we can zoom in on the plot to obtain more accurate values for the coordinate of a point on the line.

 Do Exercises 3(b) and 5(b) on page 66.

4.5 Plotting Rectangles, Squares, and Circles

In addition to points and lines, the plotting class `CPlot` can also be conveniently used to draw rectangles, squares, and circles on a plot.

The member function call

```
plot.rectangle(x, y, width, height);
```

draws a rectangle with the lower left corner at the point (x, y) with the specified width and height. A rectangle becomes a square if its width and height are the same.

The member function call

```
plot.rectanglexy(x1, y1, x3, y3);
```

draws a rectangle with lower left vertex at (x_1, y_1) and upper right vertex at (x_3, y_3) . These two points create a virtual diagonal for the rectangle.

The member function call

```
plot.circle(x, y, r);
```

draws a circle centered at the point (x, y) with the radius r .

Program 4.5 generates a graph shown in Figure 4.5 with two squares, a circle, and two points. The function call

```
plot.rectangle(-1, -1, 2, 2);
```

creates a square with the lower left corner at $(-1, -1)$ and the side length of 2. The function call

```
plot.rectanglexy(-2, -2, 2, 2);
```

creates a square with the lower left corner at $(-2, -2)$ and the upper right corner at $(2, 2)$. The function call

```
plot.circle(0, 0, 1);
```

creates a circle at the center $(0, 0)$ with the radius of 1. The function calls

```
plot.point(-0.5, 0.5);
plot.point(0.5, 0.5);
```

creates two points at $(-0.5, 0.5)$ and $(0.5, 0.5)$. In section 4.8, we will learn how to change the default type, size, and color of lines and points.

A plot is typically displayed in a rectangular area with a proper scale. The *aspect ratio* of a plot is the ratio of the length of the y-axis to the length of the x-axis. It can be set by the member function

```
plot.sizeRatio(ratio);
```

The argument `ratio` specifies the aspect ratio. The function call

```
plot.sizeRatio(1);
```

4.5. Plotting Rectangles, Squares, and Circles

```

/* File: squarecircle.ch
   Plot a square with the lower left corner at (-1, -1) and the side length 2,
   a circle with the center at (0, 0) and the radius 1.
   two points at (-0.5, 0.5) and (0.5, 0.5). */
#include <chplot.h>           // for CPlot
double x, y;                  // random points and PI
CPlot plot;

plot.title("");
plot.label(PLOT_AXIS_X, "x");
plot.label(PLOT_AXIS_Y, "y");
plot.sizeRatio(1);            // for drawing a circle with the 1:1 aspect ratio

plot.rectangle(-1, -1, 2, 2); // draw a square with the side length 2
plot.rectanglexy(-2, -2, 2, 2); // draw a rectangle with two diagonal points
                                // (-2, -2) and (2, 2)
plot.circle(0, 0, 1);         // draw a circle with the radius 1
plot.point(-0.5, 0.5);       // draw a point
plot.point(0.5, 0.5);        // draw another point
plot.plotting();

```

Program 4.5: Plotting two squares, a circle, and two points.

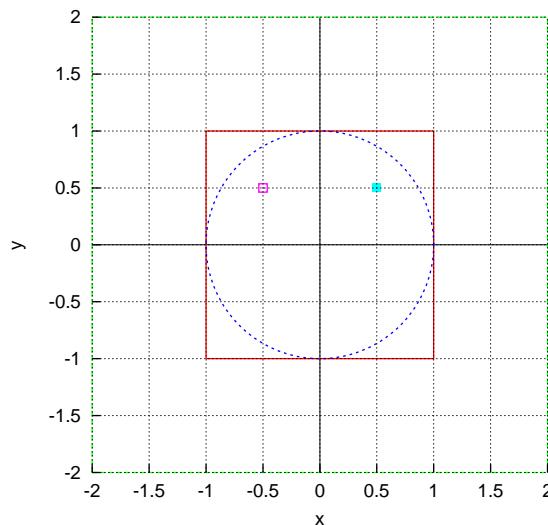


Figure 4.5: The graph with two squares, a circle, and two points, generated by Program 4.5.

4.6. Setting Axis Ranges and Tick Marks in Plots

will display a plot in a square box when the ranges for x and y are the same. This member function is called in Program 4.5 so that the square and circle will be properly shaped.



Note that for some wide screens, the aspect ratio may need to be set to 1.5 to display properly with the aspect ratio 1. You may also resize the plot window to attain different aspect ratios.

Do Exercises 6 and 7 on page 67.

4.6 Setting Axis Ranges and Tick Marks in Plots

In Program 4.2, the ranges and tick marks for the x-axis and y-axis are set automatically by the plotting class **CPlot**, based on the data for the two end points for a line. A **range** is the beginning and ending numbers shown on each axis. A **tick mark** is the interval between units on each axis. The range for the x-axis is from -20 to 120 by increment of 20 between each tick mark, as shown in Figure 4.3. The range for the y-axis is from -30 to 50 by increment of 10 between each tick mark. Sometimes, it may be desirable to set the ranges and tick marks for axes directly to make a plot more appealing.

The **axis ranges** can be set by the member function

```
plot.axisRange(axis, minimum, maximum);
```

The first argument **axis** specifies the axis. The macros **PLOT_AXIS_X** and **PLOT_AXIS_Y** can be used for **axis** to specify the x and y axes, respectively. These macros are defined in the header file **chplot.h**. The second argument **minimum** is for the minimum value on the axis. The third argument **maximum** is for the maximum value on the axis.

The tick marks on an axis can be set by the member function

```
plot.ticsRange(axis, incr);
```

Like the member function **plot.axisRange()**, the first argument **axis** specifies the axis. The second argument **incr** gives the increment between tick marks.

Program 4.6 uses these member functions to set the ranges and tick marks for x and y axes with the output plot displayed in Figure 4.6. The range for the x-axis is set from -40 to 140 by increment of 10 between each tick mark by the statements

```
plot.axisRange(PLOT_AXIS_X, -40, 140);
plot.ticsRange(PLOT_AXIS_X, 10);
```

The range for the y-axis is set from -40 to 60 by increment of 5 between each tick mark by the statements

```
plot.axisRange(PLOT_AXIS_Y, -40, 60);
plot.ticsRange(PLOT_AXIS_Y, 5);
```

Normally, you create a plot without setting the ranges and tick marks for axes first. The plotting in Ch can do a good job to automatically select appropriate ranges so that a line can be properly displayed. After you visually examine the displayed plot, if necessary, you can then modify the program to set the desired ranges and tick marks by calling the member functions **plot.axisRange()** and **plot.ticsRange()**.

Do Exercise 8 on page 67.

4.6. Setting Axis Ranges and Tick Marks in Plots

```

/* File: line2.ch
Plot the temperature relationship between Fahrenheit and Celsius
using the member function line() for x from -10 to 110.
The range of x-axis is from -40 to 140, the value between each tick is 10.
The range of y-axis is from -40 to 60, the value between each tick is 5. */
#include <chplot.h>           // for CPlot
double x1, y1, x2, y2;
CPlot plot;

plot.title("Temperature Relation");
plot.label(PLOT_AXIS_X, "Fahrenheit");
plot.label(PLOT_AXIS_Y, "Celsius");
plot.axisRange(PLOT_AXIS_X, -40, 140);
plot.axisRange(PLOT_AXIS_Y, -40, 60);
plot.ticsRange(PLOT_AXIS_X, 10);
plot.ticsRange(PLOT_AXIS_Y, 5);

/* add a line connecting (x1, y1) and (x2, y2) to the plot */
x1 = -10;
y1 = 5*(x1-32)/9;
x2 = 110;
y2 = 5*(x2-32)/9;
plot.line(x1, y1, x2, y2);
plot.plotting();

```

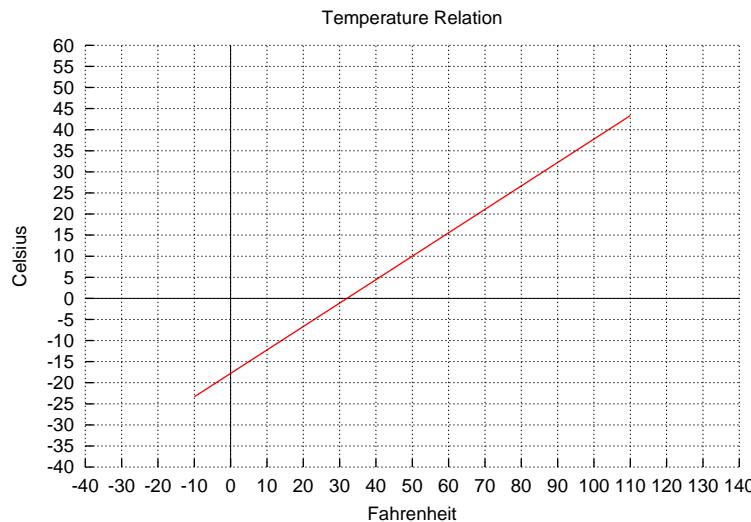
Program 4.6: Controlling the axis and tick ranges in plotting the line $y = 5(x - 32)/9$.

Figure 4.6: The temperature relationship between Fahrenheit and Celsius, generated by Programs 4.6 and 7.5 in Chapter 7.

4.7. Plotting Multiple Lines and Curves in a Single Graph

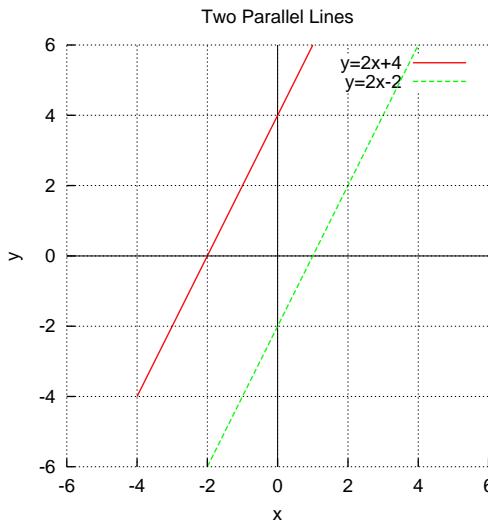


Figure 4.7: Two parallel lines $y = 2x + 4$ and $y = 2x - 2$, generated by Program 4.7.

4.7 Plotting Multiple Lines and Curves in a Single Graph

In this section, we will learn how to plot multiple lines in a single graph, which is useful to visually examine the relationship of lines.

We can call the member function **plot.line()** or other member functions multiple times to add multiple lines, curves, and other objects to the same plot. Program 4.7 calls the member function **plot.line()** twice to generate two parallel lines, represented by

$$y = 2x + 4$$

$$y = 2x - 2$$

as shown in Figure 4.7.

In general, if there are multiple lines in a plot, you may want to use legends to distinguish each line as shown in Figure 4.7. The member function **plot.legend()**, in the form

```
plot.legend("legend", datanum);
```

can be called to add a legend to the plot. The first argument "legend" is the name of the legend, what you want the legend to display. The second argument datanum is the number for the data set associated with the legend. Numbering of data set starts with zero. By default, the legends appear in the upper right corner.

In Program 4.7, the statements

```
plot.line(x1, y1, x2, y2);
plot.legend("y=2x+4", 0);
```

create the first line $y = 2x + 4$ for x from $x_1 = -4$ to $x_2 = 4$ with the legend "y=2x+4". The statements

```
plot.line(x1, y1, x2, y2);
plot.legend("y=2x-2", 1);
```

create the second line $y = 2x - 2$ for x from $x_1 = -4$ to $x_2 = 4$ with the legend "y=2x-2".

Do Exercise 9, on page 68.

4.7. Plotting Multiple Lines and Curves in a Single Graph

```

/* File: twoparallelines2.ch
   Plot two parallel lines y = 2x+4
                           y = 2x-2
   using the member line() to connect two points (-4, y1) and (4, y2).
   The range of x-axis is from -6 to 6.
   The range of y-axis is from -6 to 6 */
#include <chplot.h> /* for CPlot */
double x1, y1, x2, y2;
CPlot plot;

plot.title("Two Parallel Lines");
plot.label(PLOT_AXIS_X, "x");
plot.label(PLOT_AXIS_Y, "y");
plot.axisRange(PLOT_AXIS_X, -6, 6);
plot.axisRange(PLOT_AXIS_Y, -6, 6);
plot.sizeRatio(1);

/* add a line for y = 2x+4 connecting two points (x1, y1) and (x2, y2) */
x1 = -4;
y1 = 2*x1 + 4;
x2 = 4;
y2 = 2*x2 + 4;
plot.line(x1, y1, x2, y2);
plot.legend("y=2x+4", 0); /* add legend for y=2x+4 */

/* add a line for y = 2x-2 connecting two points (x1, y1) and (x2, y2) */
y1 = 2*x1 - 2;
y2 = 2*x2 - 2;
plot.line(x1, y1, x2, y2);
plot.legend("y=2x-2", 1); /* add legend for y=2x-2 */

plot.plotting();

```

Program 4.7: Plotting two parallel lines.

4.8 Setting Line and Point Types

Member functions `plot.line()`, `plot.rectangle`, `plot.circle`, and some other member functions such as `plot.func2D()` to be presented in the later chapter draw lines in a graph. In certain applications, you may want to draw a line with specified attributes such as width and color. You may also want to change the shape, size, and color of points. In this section, we will learn how to set attributes of lines and points.

4.8.1 Setting Line Type, Width, and Color

The member function `plot.lineType()` below can be used to change the default line type, width, and color.

```
plot.lineType(datanum, lineType, lineWidth, "blue");
```

The first argument `datanum` specifies the data set, to which the line type, width, and color apply. The second argument `lineType` is an integer index representing the line type for drawing, like whether it is dotted, dashed, or solid. The line type of value 1 is for a solid line, the default line type. The line type of value 0 is for a dotted line. Use the same value for different curves so that each curve will have the same style and same color by default. The third argument `lineWidth` with an integer value is a scaling factor for the line width. The line width is `lineWidth` multiplied by the default width. The fourth argument in the string specifies the color. The string "blue" specifies the blue color. Other colors such as "red", "green", and "grey" can also be used. In addition, the color can be specified by the RGB (red, green, and blue) value, such as "#0000ff" for color blue.

Program 4.8 generates Figure 4.8, which is similar to Figure 4.5. Comparing with Figure 4.5, the line width of the square in Figure 4.8 is 5 times thicker than the default size by the function call

```
int lineType=1, lineWidth=5;
/* ... */
plot.lineType(datanum, lineType, lineWidth, "red");
```

In addition to the change of the line width, the color of the circle is changed from the default green to the blue by the function call

```
plot.lineType(datanum, lineType, lineWidth, "blue");
```

4.8.2 Setting Point Type, Size, and Color

The member function `plot.pointType()` below can be used to change the default point type, size, and color.

```
plot.pointType(datanum, pointType, pointSize, "black");
```

Similar to the member function `plot.lineType()`, the first argument `datanum` specifies the data set, to which the point type, size, and color apply. The second argument `pointType` is an integer representing the index of the desired point type. The point type of value 7 is for a solid point. Use the same value for different points so that each point will have the same style and same color by default. The third argument `pointSize` with an integer value is a scaling factor for the point size. The point size is `pointSize` multiplied by the default size. The fourth argument in the string specifies the color.

As shown in Figure 4.8, Program 4.8 sets the two points with the solid points, size 1, and black color by the statements

```
int pointType=7, pointSize=1;
/* ... */
plot.pointType(datanum, pointType, pointSize, "black");
```

4.8. Setting Line and Point Types

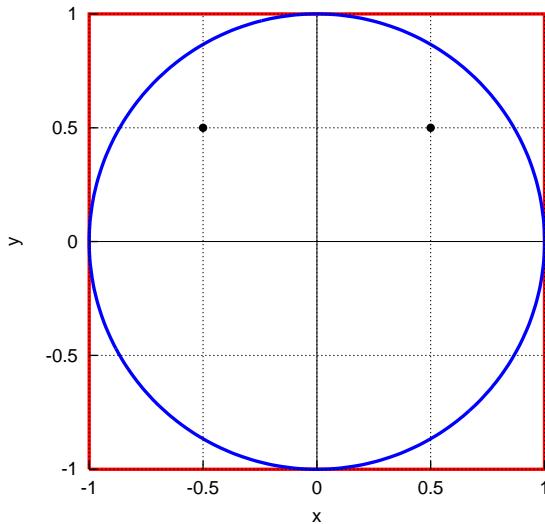


Figure 4.8: The graph with a square, a circle, and two points with modified line and point attributes, generated by Program 4.8.

```
/* File: linepointtypes.ch
   Plot a square with the lower left corner at (-1, -1) and the side length 2,
   a circle with the center at (0, 0) and the radius 1.
   two points at (-0.5, 0.5) and (0.5, 0.5).
   The line type for the square and circle is solid line and
   the line width is 5 times the normal size.
   The point type is solid dot with the normal size. */
#include <chplot.h>           // for CPlot

int lineType=1, lineWidth=5;    // solid line with 5 pixel width for the square and circle
int pointType=7, pointSize=1;   // solid point with 1 pixel size for points
CPlot plot;

plot.title("");
plot.label(PLOT_AXIS_X, "x");
plot.label(PLOT_AXIS_Y, "y");
plot.sizeRatio(1);             // for drawing a circle with the 1:1 aspect ratio

plot.rectangle(-1, -1, 2, 2);  // draw a square with the side length 2
plot.lineType(0, lineType, lineWidth, "red");    // red color

plot.circle(0, 0, 1);         // draw a circle with the radius 1
plot.lineType(1, lineType, lineWidth, "blue");    // blue color

plot.point(-0.5, 0.5);       // draw a point
plot.pointType(2, pointType, pointSize, "black"); // black color

plot.point(0.5, 0.5);        // draw another point
plot.pointType(3, pointType, pointSize, "black");

plot.plotting();
```

Program 4.8: Plotting a square, a circle, and two points with line and point attributes.

4.8. Setting Line and Point Types

For detailed information about the member functions `lineType()` and `pointType()`, see ***Ch Reference Guide*** in the file C:\Ch\docs\chref.pdf.

 Do Exercise 10 on page 69.

Application: Plotting a Rectangle

Problem Statement:

Write an interactive program `plotrectangle.ch` to plot a rectangle. The program accepts the user input for the coordinates (x, y) for the lower left corner, width, height, line width, and color of the rectangle.

Program 4.9 calls the member function

```
plot.rectangle(x, y, width, height); // draw a rectangle
```

to draw a rectangle. The line width and color of the rectangle are set by the statement

```
plot.lineType(0, lineType, lineWidth, color); // line type
```

The aspect ratio between the y-axis and x-axis is set by the statement

```
plot.sizeRatio(height/width); // set the aspect ratio
```

```
/* File: plotrectangle.ch
   Plot a rectangle using
   plot.rectangle(x, y, width, height);
   plot.lineType(0, lineType, lineWidth, color);
   The user inputs x, y, width, height, lineWidth, and color. */
#include <chplot.h> // for CPlot

CPlot plot;
double x, y, width, height; // the lower left corner (x, y), width, and height
int lineType=1, lineWidth; // line type and line width
string_t color; // color

/* get the user input */
printf("Welcome to the Rectangle Plotter\n");
printf("Enter x y width height\n");
scanf("%lf%lf%lf%lf", &x, &y, &width, &height);
printf("Enter the line width [1-10]\n");
scanf("%d", &lineWidth);
printf("Enter the color for the rectangle\n");
scanf("%s", &color);

plot.title("");
plot.label(PLOT_AXIS_X, "x");
plot.label(PLOT_AXIS_Y, "y");
plot.sizeRatio(height/width); // set the aspect ratio
plot.rectangle(x, y, width, height); // draw a rectangle
plot.lineType(0, lineType, lineWidth, color); // line type
plot.plotting();
```

Program 4.9: Interactive plotting a rectangle.

4.9. Plotting Texts and Arrows

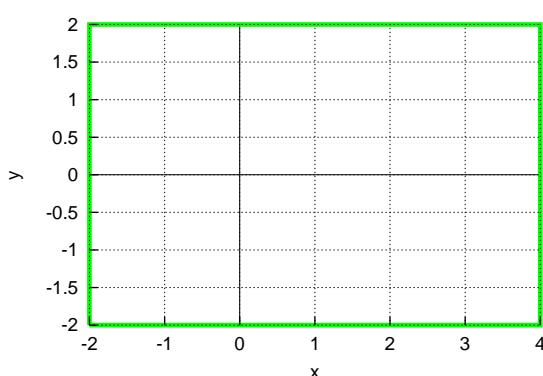


Figure 4.9: The plot generated interactively by Program 4.9.

A sample interactive execution of Program 4.9 is given below.

```
Welcome to the Rectangle Plotter
Enter x y width height
-2 -2 6 4
Enter the line width [1-10]
7
Enter the color for the rectangle
green
```

The plotted rectangle on the screen is shown in Figure 4.9. The coordinates for the lower left corner of the rectangle is $(-2, 2)$. The width, height, line width, and color of the rectangle are 6, 4, 7 pixels, and green, respectively.

Do Exercises 11 and 12 on page 69.

4.9 Plotting Texts and Arrows

As we have learned, the plotting class **CPlot** can be conveniently used to draw various objects. In this section, we will learn how to create text and arrows in the plot and their applications.

The member function call

```
plot.text("string", PLOT_TEXT_CENTER, x, y);
```

draws a string centered at the point (x, y) so that you can add text to the plot. If the macro **PLOT_TEXT_CENTER** is used, the specified location is the center of the text string. If the macro **PLOT_TEXT_LEFT** is used, the specified location is the left side of the text string. For the macro **PLOT_TEXT_RIGHT**, the specified location is the right side of the text string. The member function call

```
plot.arrow(x_tail, y_tail, x_head, y_head);
```

adds an arrow to a plot. The arrow points from (x_tail, y_tail) to (x_head, y_head) . This member function can be used to add arrows to the x and y axes.

Various plotting features are demonstrated in Program 4.10 with the generated graph shown in Figure 4.10. Program 4.10 first draws a line representing the linear relation between the temperature Celsius and temperature Fahrenheit, using two points $(-10, -23.33)$ and $(110, 43.33)$ by the member function call

4.10. Saving Plot in a File

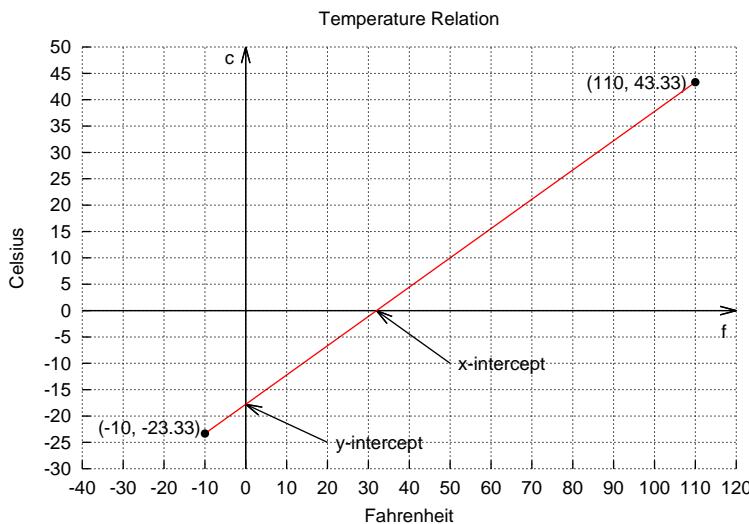


Figure 4.10: The graph with a line, points, arrows, and text, generated by Program 4.10.

```
plot.line(-10, -23.33, 110, 43.33);
```

Then, it draws two solid end points by the statements

```
plot.point(-10, -23.33);
plot.pointType(1, pointType, pointSize);
plot.point(110, 43.33);
plot.pointType(2, pointType, pointSize);
```

The arrow and text for the x-coordinate are added by the statements

```
plot.arrow(-40, 0, 120, 0);
plot.text("f", PLOT_TEXT_CENTER, 117, -4);
```

The arrow points from the point $(-40, 0)$ to the point $(120, 0)$ with the letter '*f*' at the point $(117, -4)$. The arrow and label for the x-intercept are added by the statements

```
plot.arrow(50, -10, 32, 0);
plot.text("x-intercept", PLOT_TEXT_LEFT, 52, -10);
```

The arrow points from the point $(50, -10)$ to the x-intercept $(32, 0)$. The text "x-intercept" is displayed at the left of the position $(52, -10)$.

The arrow and text for the y-intercept and y-intercept $(0, -17.78)$ are added similar. Finally, the labels " $(-10, -23.33)$ " and " $(110, 43.33)$ " for the coordinates of two end points are added by the statements

```
plot.text("( -10, -23.33 )", PLOT_TEXT_RIGHT, -11, -22.3);
plot.text("( 110, 43.33 )", PLOT_TEXT_RIGHT, 108, 43.3);
```

Do Exercise 13 and on page 69.

4.10 Saving Plot in a File

A plot not only can be displayed on the computer screen, but also exported in a variety of file formats for various applications. A plot can be saved in a file by the member function call

4.10. Saving Plot in a File

```

/* File: coordinates.ch
   Plot the temperature relationship between Fahrenheit and Celsius
   using the member function line() for x from -10 to 110 with two points for a line.
   The range of x-axis is from -40 to 120, the value between each tick is 10.
   The range of y-axis is from -30 to 50, the value between each tick is 5. */
#include <chplot.h>           // for CPlot
CPlot plot;
int pointType=7, pointSize = 1;

plot.title("Temperature Relation");
plot.label(PLOT_AXIS_X, "Fahrenheit");
plot.label(PLOT_AXIS_Y, "Celsius");
plot.axisRange(PLOT_AXIS_X, -40, 120);
plot.axisRange(PLOT_AXIS_Y, -30, 50);
plot.ticsRange(PLOT_AXIS_X, 10);
plot.ticsRange(PLOT_AXIS_Y, 5);

/* add a line with two points to the plot */
plot.line(-10, -23.33, 110, 43.33);
/* add two points to the plot */
plot.point(-10, -23.33);
plot.pointType(1, pointType, pointSize);
plot.point(110, 43.33);
plot.pointType(2, pointType, pointSize);

/* add an arrow and text for the x-coordinate */
plot.arrow(-40, 0, 120, 0);
plot.text("f", PLOT_TEXT_CENTER, 117, -4);

/* label x-intercept */
plot.arrow(50, -10, 32, 0);
plot.text("x-intercept", PLOT_TEXT_LEFT, 52, -10);

/* add an arrow and text for the y-coordinate */
plot.arrow(0, -30, 0, 50);
plot.text("c", PLOT_TEXT_CENTER, -4, 48);

/* label y-intercept */
plot.arrow(20, -25, 0, -17.78);
plot.text("y-intercept", PLOT_TEXT_LEFT, 22, -25);

/* display coordinates of two points */
plot.text("(-10, -23.33)", PLOT_TEXT_RIGHT, -11, -22.3);
plot.text("(110, 43.33)", PLOT_TEXT_RIGHT, 108, 43.3);

plot.plotting();

```

Program 4.10: Plotting a line, points, arrows, and text.

4.11. Chapter Summary

```

/* File: pointsjpg.ch
   Plot the temperature relationship between Fahrenheit and Celsius using five points.
   Save the plot in the file points.jpg in JPEG file format */
#include <chplot.h>           // for CPlot
CPlot plot;                   // declare the variable plot

plot.title("Temperature Relation"); // title of the plot
plot.label(PLOT_AXIS_X, "Fahrenheit"); // x-label of the plot
plot.label(PLOT_AXIS_Y, "Celsius"); // y label of the plot

/* add five data points for plotting */
plot.point(-10, -23.33);
plot.point(20, -6.67);
plot.point(50, 10.00);
plot.point(80, 26.67);
plot.point(110, 43.33);

/* save plot in the file points.jpg in JPEG file format */
plot.outputType(PLOT_OUTPUTTYPE_FILE, "jpeg", "points.jpg");
plot.plotting();

```

Program 4.11: Saving the plot in the file points.jpg . jpg in the JPEG file format.

```
plot.outputType(PLOT_OUTPUT_TYPE_FILE, "format", "filename");
```

The member function calls below show how to save a plot in GIF and JPEG files `plot.gif` and `plot.jpg`, respectively.

```

/* save in the file plot.gif in GIF file format */
plot.outputType(PLOT_OUTPUTTYPE_FILE, "gif", "plot.gif");
/* save in the file plot.jpg in JPEG file format */
plot.outputType(PLOT_OUTPUTTYPE_FILE, "jpeg", "plot.jpg");

```

For example, the statement

```
plot.outputType(PLOT_OUTPUTTYPE_FILE, "jpeg", "points.jpg");
```

in Program 4.11 saves the plot, as shown in Figure 4.1, in the file `points.jpg` in the JPEG file format in the same folder where the program `points.jpg.ch` is located.

 Do Exercise 14 on page 69.

4.11 Chapter Summary

4.11.1 Programming Tips

Good Programming Practice

1. Call the plotting member function

```
plot.plotting();
```

after all other member functions.

4.12. Exercises

4.11.2 Terminology**General Concepts**

graphical visualization	plotting
-------------------------	----------

The Plotting Class CPlot

chplot.h	CPlot	CPlot::arrow()
CPlot::axisRange()	CPlot::circle()	CPlot::line()
CPlot::label()	CPlot::legend()	CPlot::plotting()
CPlot::lineType()	CPlot::outputType()	CPlot::rectangle()
CPlot::point()	CPlot::pointType()	
CPlot::rectanlexy() CPlot::sizeRatio()	CPlot::text()	
CPlot::ticsRange()	CPlot::title()	file format GIF
file format PNG	header	hedader file
PLOT_AXIS_X	PLOT_AXIS_Y	PLOT_TEXT_CENTER
PLOT_TEXT_LEFT	PLOT_TEXT_RIGHT	PLOT_OUTPUTTYPE_FILE

4.12 Exercises

1. One mile is 1.6093 kilometers. (a) Write a program `mile2km.ch` to plot the following points

$$(1, 1.6093), (3, 4.8279), (5, 8.0465), (10, 16.093), (20, 32.186), (30, 48.279), \\ (40, 64.372), (50, 80.465), (60, 96.558), (70, 112.651), (80, 128.744).$$

in a graph showing the relation of miles versus kilometers. The title of the plot should be “kilometer=1.6093*mile”. The labels on the x-axis and y-axis should be “miles” and “kilometers”, respectively. (b) Copy and paste the displayed plot into a Word file. Then, print out the plot.

2. A robot moves based on the following relation of the position versus time

$$p(t) = 0.25t + 1.25$$

The time and corresponding positions of a robot are recorded in Table 4.2 in an experiment.

Table 4.2: Positions of a robot versus time.

time (seconds)	0.00	2.00	4.00	6.00	8.00	10.00
position (meters)	1.25	1.75	2.25	2.75	3.25	3.75

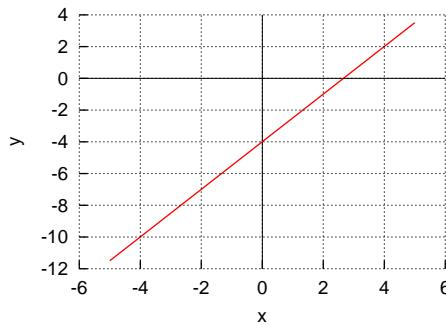
(a) Write a program `robotpos.ch` to plot the trajectory of the robot based on the data in this table. (b) Copy and paste the displayed plot into a Word file. Then, print out the plot.

3. (a) Write a program `linec.ch` to find two points for $x = -5$ and $x = 5$ for the following linear equation.

$$y = 1.5x - 4$$

Draw a line to connect these two points. The plot shall have no title. The labels on the x-axis and y-axis should be “x” and “y”. (b) Find the x-intercept and y-intercept for this equation.

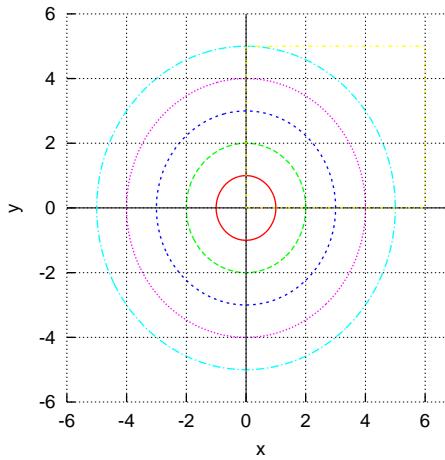
4.12. Exercises



4. A robot moves based on the following linear relation of the position in meters versus time in seconds

$$p(t) = 0.25t + 1.25$$

- (a) Write a program `robotpos2.ch` to plot the trajectory of the robot using two points when time t is 0 and 5 seconds through the member function `plot.line()`. (b) Write a program `robotpos3.ch` to plot the trajectory of the robot using 100 points when time t is 0 and 5 seconds through the member function `plot.expr()`.
5. (a) Write a program `exprpoly2.ch` to plot the polynomial $y = -2x^2 - 20x + 55$ for x from -20 to 10 using the member function `plot.expr()`. (b) Move the cursor on the screen for the polynomial to obtain the value for y at x of 5 .
6. Write a program `circlerect.ch` to draw circles with radius of 1, 2, 3, 4, and 5 at the center $(0, 0)$. Draw a rectangle with its lower left corner at $(0, 0)$, and width of 6 and height of 5 as shown in the illustration below.



7. Write a program `design.ch` to design a graph with at least 5 circles and 5 lines, and some text.
8. The cost for shipping Priority Overnight packages weighing 1 lb is modeled by the following linear equation

$$y = 2.8x + 21.05$$

where x is the number of pounds and y the cost in dollars. Write a computer program `mailcost.ch` to calculate the cost of shipping packages of 3 lb and 5 lb, and plot the mailing cost versus weight, as shown in Figure 4.11.

4.12. Exercises

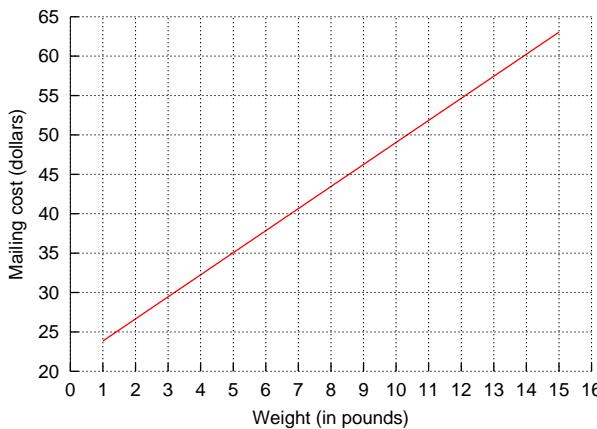


Figure 4.11: The mailing cost versus weight modeled by the equation $y = 2.8x + 21.5$.

9. A line can be represented by an equation in *slope-intercept* form

$$y = mx + b \quad (4.2)$$

where m is the slope and b is the y -intercept. For example, for the line in equation (4.3) below

$$y = 2x + 5 \quad (4.3)$$

its slope is 2. The line intercepts with the y -axis at 5, as shown in Figure 4.12. If the slopes of two lines are the same, the two lines are parallel. For example, the line below in equation (4.4)

$$y = 2x + 10 \quad (4.4)$$

is parallel to the line in equation (4.3). But, it intercepts the y -axis at 10. Two lines intersect when they contain the same point. The line below in equation (4.5)

$$y = -3x + 15 \quad (4.5)$$

intersects the line in equation (4.3) at the point $(2, 9)$ and with the line in equation (4.4) at the point $(1, 12)$. Write a program `lines.ch` to draw three lines formulated in equations (4.3) to (4.5) as shown in Figure 4.12.

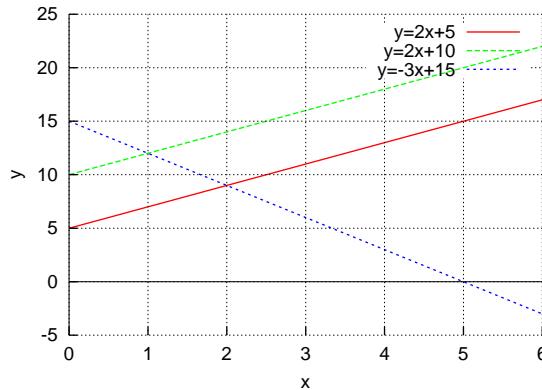
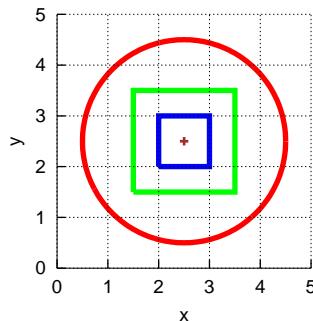


Figure 4.12: Three lines with two parallel lines.

4.12. Exercises

10. Write a program `shapes.ch` to plot the figure shown in the illustration below.



11. (a) Run the program `plotrectangle.ch` in Program 4.9. (b) Comment out the statement

```
plot.sizeRatio(height/width);
```

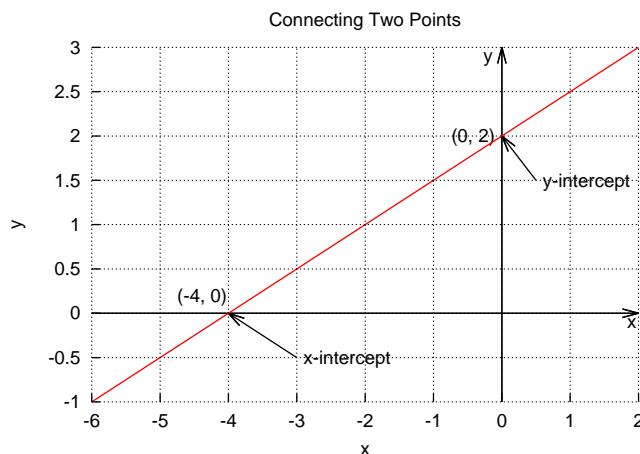
and run the program. (c) Use the statement

```
plot.sizeRatio(1);
```

and run the program again. What are the differences in the generated plots?

12. Modify the program `plotrectangle.ch` in Program 4.9 as a program `plotcircle.ch` to plot a circle. The program accepts the user input for the coordinates (x, y) for the center, radius, line width, and color of the circle.

13. Write a program `linetwopoints.ch` to draw a graph as shown in the illustration below.



14. Modify the program `shapes.ch` developed in Exercise 10 as a new program `shapes.jpg.ch` to save the plot in the file `shapes.jpg` in the JPEG file format.

CHAPTER 5

Relations and Making Decisions

So far the programs we have written are pretty simple. They all consist of a series of actions performed in sequence. For more complicated problems, they may require that a decision take place inside the program. In this chapter, we will learn **selection statements** which are executed when a condition is met. We will also learn relational operators and logical operators which are commonly used in making decisions in selection statements. An **algorithm** consists of a set of actions and the order in which they are to be performed. Algorithms can be defined in terms of certain control structures in C, which are classified as **sequential**, which we have used previously, **selective**, or **repetitive**. We will learn repetition statements in Chapter 6.

5.1 Relational Operators

Prerequisite: Understanding variable types, program structure, and arithmetic operators

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D4.1

Objective: Use relational operators to test the relationship between values/variables.

For operations using relational operators given in Table 5.1, the result is always an integer with a logical value of 1 or 0. In the context of computer programming, 1 means **true** and the 0 means **false**. The result is 1 if the comparison is correct, and 0 otherwise. For example,

```
> int i = 5, j = 3
> i < j
0                         // false
> i <= j
0                         // false
> i == j
0                         // false
```

5.1. Relational Operators

Table 5.1: Relational operators

operator	operation	description
<	$x < y$	is less than
\leq	$x \leq y$	is less than or equal to
$=\!=\!$	$x == y$	is equal to
\geq	$x \geq y$	is greater than or equal to
>	$x > y$	is greater than
\neq	$x \neq y$	is not equal to

```

> j == j
1                         // true
> i > j
1                         // true
> i >= j
1                         // true
> i != j
1                         // true
> i != i
0                         // false
> printf("i != j is %d", i != j)
i != j is 0
  
```

 Do Exercise 1 on page 86.

Application: A Driver Eligibility Test

Problem Statement:

Write a program to check if a person is old enough to drive. It is assumed that a person of 16 years old is eligible to obtain a driver license. The program should let the user to enter his/her name and age.

5.1. Relational Operators

```

/* File: drivertest.ch
   Check if a person is old enough to drive */

/* declare variables */
string_t name;           /* name */
int age;                 /* age */

/* get the user input */
printf("What's your name?\n");
scanf("%s", &name);
printf("How old are you?\n");
scanf("%d", &age);

if(age > 15) {
    printf("%s, you can get a license.\n", name);
    printf("Happy Trails!\n");
}
else {
    printf("Sorry, %s, you are too young to get a license.\n", name);
}

```

Program 5.1: Checking if a person is old enough to drive.

Program 5.1 can be used to check if a person is old enough to drive. The variable `name` of string type is used to hold a name and the variable `age` is for age. If the value of the variable `age` is larger than 15, the expression `age > 15` is 1. Otherwise, it is 0. In Program 5.1, the following **if-else** structure is used to handle two different scenarios.

```

if(age > 15) {    // if (age >15) is true,
    statement1; // execute this statement1
}
else {           // else,
    statement2; // execute this statement2
}

```

If the person is older than 15, the program displays a message to inform the user that you can get a license. Otherwise, it displays a different message indicating that you are too young to get a license. The details about the **if** statement will be described in the next section.

An interactive execution of Program 5.1, when the condition expression of the **if** statement is true, is shown below:

```

What's your name?
John
How old are you?
17
John, you can get a license.
Happy trails.

```

Another execution of Program 5.1, when the condition expression of the **if** statement is false, is shown below:

```

What's your name?
Sue

```

5.2. Selection Statements for Decision Making

```
How old are you?
14
Sorry, Sue, you are too young to get a license.
```

 Do Exercise 2 on page 86.

The relational operators `==` and `!=` can also be applied to compare two strings. A sample application using these operators for strings will be presented in section 5.3.

5.2 Selection Statements for Decision Making

Prerequisite: Understanding program structure

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4, RST.6-12.7

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.1, D5.5

Objective: Understand how to use selection statements in a computer program. Debug programs with selection statements using ChIDE. Understand the need for readable code and use the indent tool provide by ChIDE.

Selection statements allow a program to execute different tasks based on the results of relational and logical operations. We will cover the following selection statements: **if**, **if-else**, and **else if** statements.

5.2.1 The **if** Statement

The syntax of an **if** statement is as follows:

```
if(expression) {
    statement;
}
```

When an **if** statement is executed, the controlling expression will be evaluated first. In the context of structured programming, the true means not equal to 0 and the false means 0.

With an **if** statement, a substatement is executed if the expression returns a true value. If a false value is returned, then the substatement is skipped and the program execution moves on to the next line.



One of common mistakes for beginners in using the **if** statement is to write

```
if(i=5)
```

instead of

```
if(i==5)
```

In the case of the first example, the result of the conditional expression is 5, therefore, the condition is always evaluated as true because 5 is not equal to zero.

5.2. Selection Statements for Decision Making

5.2.2 The if-else Statement

The syntax of an **if-else** statement is as follows:

```
if(expression) {
    statement1;
}
else {
    statement2;
}
```

The **if-else** statement is commonly used for decision making. We have already used the **if-else** statement in Program 5.1. Within **if-else** statements, there is a separate statement for both a true and false value for the controlling expression. If the expression returns a true value, then `statement1` would be executed. If a false value was returned, `statement2` would be executed.

Application: Calculating the Daily Wage**Problem Statement:**

Hourly employees at a company are paid \$20 per hour for less than or equal to eight hours worked per day. Any time over this amount is paid at 1.5 times the normal rate. The company withholds 30% from the gross pay for the federal and state income tax. Write a program `wage.ch` to determine the gross pay, deducted tax, and net pay for an employee based on the user input of the hours worked for a day.

If the hours worked for an employee are less than or equal to eight hours, the daily gross pay is $20t$ with time t in hours. If the hours worked are more than eight hours, the payment for the first eight hours is $20*8$ and the payment for the time over eight hour is $1.5 * 20(t - 8)$ for t larger than 8. Therefore, the daily gross pay in this case can be expressed as

$$20 * 8 + 1.5 * 20(t - 8) = 30t - 80$$

Then, the daily gross pay for an employee can be formulated as follows:

$$p(t) = \begin{cases} 20t & \text{if } t \leq 8 \\ 30t - 80 & \text{if } t > 8 \end{cases}$$

The deducted tax is the result of multiplication of 0.3 by the gross pay. The gross pay less the deducted tax is the net pay.

5.2. Selection Statements for Decision Making

```

/* File: wage.ch
   Calculate the gross pay, deducted tax, and net pay
   The formula for the gross pay depends on t <= 8 or t > 8 hours */

/* declare variables */
double t, grosspay, netpay, tax;

/* get the user input for the hours worked */
printf("Welcome to the Wage Calculator\n");
printf("Please enter the hours worked\n");
scanf("%lf", &t);

/* process the payment */
if(t <= 8) { /* when time t is less or equal to 8 hours */
    grosspay = 20*t;
}
else {          /* when time t is greater than 8 hours */
    grosspay = 30*t - 80;
}

tax = 0.3*grosspay;
netpay = grosspay - tax;

/* display the payment as output */
printf("    gross pay: $%.2lf\n", grosspay);
printf("deducted tax: $%.2lf\n", tax);
printf("    net pay: $%.2lf\n", netpay);

```

Program 5.2: Calculating the wage using **if-else** structure.

This problem can be solved with Program 5.2, which uses an **if-else** statement to determine how the gross pay p is calculated. First, the program uses the function `scanf()` to read in the time. Based on the value of the input time, the gross pay will be calculated using different formulas. If the specified time is less than or equal to eight hours, p is $20t$. Otherwise, p is equal to $30t - 80$. The result of the net pay is then displayed. Program 5.2 can be executed as shown below.

```

Welcome to the Wage Calculator
Please enter the hours worked
5
    gross pay: $100.00
deducted tax: $30.00
    net pay: $70.00

```

 Do Exercises 3 and 4 (a) on page 86.

5.2.3 Debugging Programs with Selection Statements Using ChIDE

Running a program in the debug mode in ChIDE step-by-step as described in section 2.4 is very helpful for understanding the working principle of selection statements. You can examine the conditional expression of the selection statements to see which branch of the selection statements is executed based on the condition.

You can run the program `wage.ch` in ChIDE using the command `Step` to see which substatement of the **if** statement is executed.

 Do Exercise 4 (b) on page 86.

5.3. Logical Operators

Table 5.2: Logical operators

operator	operation	description
<code>&&</code>	<code>x && y</code>	logical AND operator
<code> </code>	<code>x y</code>	logical inclusive OR operator

5.2.4 Programming Style and Indenting Programs Using ChIDE

As we described before, for readability and software maintenance, statements inside a function shall be properly indented. Indentation is especially important for a program with many nested loops, which will be described later in this chapter. Indentation needs to be consistent for a program with a fixed number of blank spaces. Each indentation in most source code presented in this book uses four blank space characters. The use of horizontal tabs for indentation is not recommended because it takes too much space in code with many nested loops and blocks. Also, some word processors will treat a horizontal tab as a single white space. Hardcopy of source code without proper indentation may be difficult to read.

Programs edited in ChIDE can be properly indented using an indentation utility program. When you click the command Tools->Indent on the toolbar, the program in the current editing pane will be properly indented. You can also right click the file name on the tab bar, located below the debug bar, and select Indent to indent the program in the editing pane.

 Do Exercise 4 (c) on page 86.

5.3 Logical Operators

Prerequisite: Understanding variable types, program structure, arithmetic and relational operators

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D4.1

Objective: Use logical operators to test the relationship between the results of 2 or more relational operations in a Ch program.

Congratulations! You are now ready to make your programs “life-like” by creating operations that will make “choices” based on certain conditions. This is done through the use of logical operators, as listed in Table 5.2. Table 5.3 summarizes the results of all the logical operations.

The logical AND operator (`&&`) can be used to check whether both the conditions of its two operands are true. If both conditions are true, then the operation returns true. Otherwise, the operation is false. For example,

```

> 1 && 1      // both conditions are true
1
> 1 && 0      // one condition is true
0
> 0 && 1      // one condition is true
0

```

5.3. Logical Operators

Table 5.3: Logical operations

x	y	x && y	x y
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	1

```
> 0 && 0      // both conditions are false
0
```

For the logical OR (||), either one or both of its operands must be true for the operation to be true. For example,

```
> 1 || 1      // both conditions are true
1
> 1 || 0      // one condition is true
1
> 0 || 1      // one condition is true
1
> 0 || 0      // both conditions are false
0
```

The logical operators are often used together with relational operations. For example,

```
> int i = 6, j = 3
> (i > 0) && (i < 5)    // evaluated as (1 && 0)
0
> (i > 0) || (i < 5)    // evaluated as (1 || 0)
1
```

Logical operators are typically used to form more complex conditions for an **if** statement. Using logical operators in this way eliminates the need for nested **if** statements. For example,

```
if((a < b) && (c < d))
    statement;
```

is equivalent to

```
if(a < b) {
    if(c < d)
        statement;
}
```

Precedence of relational and logical operators along with arithmetic operators, negation operator, and assignment operator are listed in Table 5.4. The increment ++ and decrement -- will be introduced in Chapter 6. Because logical operators have lower precedence than relational operators as shown in Table 5.4, one can write the previous **if** statement

```
if((a < b) && (c < d))
    statement;
```

as

5.3. Logical Operators

Table 5.4: Precedence and associativity of operators

Operators	Associativity
<code>++ -- - (negation)</code>	right to left
<code>* / %</code>	left to right
<code>+ -</code>	left to right
<code>< <= > >=</code>	left to right
<code>== !=</code>	left to right
<code>&&</code>	left to right
<code> </code>	left to right
<code>=</code>	right to left

```
if(a < b && c < d)
    statement;
```

Application: Determining if a Student Can Watch a Movie

Problem Statement:

A student is allowed to watch movies only on Saturday or Sunday. Write a program `movie.ch` to check if the student can watch a movie. When the student enters a response to a prompt, the program will tell if he/she can watch a movie.

The decision for watching a movie can be evaluated by the following condition structure.

```
if(is_Saturday || is_Sunday)
    you_can_watch_movie
else
    you_cannot_watch_movie
```

5.3. Logical Operators

```

/* File: movie.ch
   Students are allowed to watch movies only on Saturday or Sunday.
   This program check if you can watch a movie or not. */

/* declare variables */
string_t name; /* name */
string_t day; /* Monday, Tuesday, Wednesday, ..., Sunday */

/* get the user input of name and day of the week */
printf("What's your name?\n");
scanf("%s", &name);
printf("What day is today [Monday, Tuesday, etc.]?\n");
scanf("%s", &day);

/* If Saturday or Sunday */
if(day == "Saturday" || day == "Sunday") {
    printf("\nHi %s,\n", name);
    printf("Today is %s. You can watch a movie.\n", day);
    printf("Enjoy your time!\n");
}
else {
    printf("\nHi %s,\n", name);
    printf("Today is %s.\n", day);
    printf("You have to study and cannot watch a movie. Sorry.\n");
}

```

Program 5.3: Determining if a student can watch a movie.

In Program 5.3, the variable name of string type is used to hold the name of students. The variable day of string type is for the day of the week. The relational operator == is used to compare two strings. When the value of the variable day is either for "Saturday" or "Sunday", the condition expression inside the **if** statement below will be true and the code block will be executed.

```

if(day == "Saturday" || day == "Sunday") {
    printf("\nHi %s,\n", name);
    printf("You can watch a movie today.\n");
    printf("Enjoy your time!\n");
}

```

An interactive execution of Program 5.3 is shown below:

```

What's your name?
What day is today [Monday, Tuesday, etc.]?
Saturday

Hi John,
Today is Saturday. You can watch a movie.
Enjoy your time!

```

 Do Exercises 5, 6, and 7 on page 87.

5.3. Logical Operators

Application: Determining a Leap Year

Problem Statement:

A given year is a leap year if one of the following two conditions are satisfied: (a) if it divides exactly by four, but cannot be divided exactly by 100 or (b) if it divides exactly by 400. For example, 2012 is a leap year because it can be divided exactly by four, but cannot be divided exactly by 100. 2000 is also a leap year because it divides exactly by 400. On the other hand, neither 2100 nor 2200 is a leap year. Write a program to determine if a given year read from the user input is a leap year or not.

A given year can be represented using a variable `year` of **int** type. The modulus operator `%` can be used to determine if an integer can be divided exactly by another integer. The remainder of the modulus operation `year%4` is zero if `year` can be divided exactly by four. The remainder of the modulus operation `year%100` is not zero if `year` cannot be divided exactly by 100. Therefore, the condition (a) for a leap year can be expressed using the relational operators `==` and `!=` along with the logical AND operator `&&` in the following C expression:

```
(year%4 == 0) && (year%100 != 0)
```

If a given year satisfies the condition (a) as a leap year, the above expression evaluates to 1 (true). The parentheses in the above expression are just for clarity. The modulus operator `%` has higher precedence than relational operators as shown in Table 5.4. The relational operators `==` and `!=` have higher precedence than the logical AND operator `&&`. Therefore, the above expression can be written without parentheses as follows:

```
year%4 == 0 && year%100 != 0
```

Although white spaces in an expression are ignored when the program is processed, they can make the code more readable. For example, the following expression will be less readable than the previous two expressions:

```
year % 4 == 0 && year % 100 != 0
```

If a year divides exactly by 400 for the condition (b) for a leap year, the relational expression

```
year%400 == 0
```

evaluates to 1. If either the condition (a) or condition (b) is true, the value of the following C expression evaluates to 1 (true):

```
year%4 == 0 && year%100 != 0 || year%400 == 0
```

5.4. The **else if** Selection Statement and Early Exit of a Program

```

/* File: leapyear.ch
   Determine if a year input from the terminal is a leap year */

int year;    /* year (input from the user) */

/* prompt the user for input */
printf("Please input a year\n");
scanf("%d", &year);

/* determine if the year is a leap year or not, and display the output */
if(year%4 == 0 && year%100 != 0 || year%400 == 0) {
    printf("%d is a leap year.\n", year);
}
else {
    printf("%d is not a leap year.\n", year);
}

```

Program 5.4: Determining if a given year is a leap year.

Program 5.4 is designed using the above logical expression as the conditional expression of an **if** statement. If the conditional expression evaluates to 1 (true) for a given year, it is displayed as a leap year. Otherwise, it is displayed as a non-leap year. An interactive execution of Program 5.4 is shown below:

```

Please input a year
2012
2012 is a leap year.

```

 Do Exercise 8 on page 87.

5.4 The **else if** Selection Statement and Early Exit of a Program

The syntax of the **else if** statement is as follows:

```

if(expression1) {
    statement1;
}
else if (expression2) {
    statement2;
}
else if (expression3) {
    statement3;
}
else {
    statement4;
}

```

5.5. Chapter Summary

The **if-else** statement has two options to select. The **else-if** statements are useful when more than two options are needed. In this regard, an **else if** statement can be thought of as an extension of an **if-else** statement.

For instance, the application example on calculating the daily wage on page 74, because daily worked hours cannot be less than 0 or greater than 24, the formula for calculating the gross pay can be modified slightly as follows:

$$p(t) = \begin{cases} 20t & \text{if } 0 \leq t \leq 8 \\ 30t - 80 & \text{if } 8 < t \leq 24 \end{cases}$$

In this case, if the input for time t is a negative value or greater than 24, it is an invalid input. The algorithm is implemented in the program `grosspay.ch` listed in Program 5.5 using an **if-else if-else** structure. The mathematical condition $0 \leq t \leq 8$ for t greater than 0 and less than 8 is translated into C code as $(0 <= t \&& t <= 8)$. When the input time is less than 0 or greater than 24, the program will print an error message and exit. In this case, no payment information is printed.

Typically, a successful program execution terminates when the last statement in the program is executed. The function `exit()` called by the statement

```
exit (-1);
```

inside the **else** statement block provides an early exit for the program if the user input for the time is less than 0 or larger than 24.

Program 5.5 also generates a plot for the relation between the hours worked and gross pay, as shown in Figure 5.1. Two separate lines are used to represent the piece-wise linear relation between the hours worked and gross pay. The first line connects the points $(0, 0)$ and $(8, 20*t)$ with t equal 8. The second line connects the point $(8, 30*t-80)$ with t equal to 8 and the point $(24, 30*t-80)$ with t equal to 24. A point is created at the coordinates for the hour worked and the gross pay. An interactive execution of the program `grosspay.ch` with the user input of 7 worked hours is shown below.

```
Welcome to the Wage Calculator
Please enter the hours worked
7
gross pay: $140.00
deducted tax: $42.00
net pay: $98.00
```

Figure 5.1 shows the generated plot with a point at $(7, 140)$.

 Do Exercises 9, 10, 11, and 12, on page 87.

5.5 Chapter Summary

5.5.1 Programming Tips

Good Programming Practice

1. Indent the body of selection and repetition statements. For example,

```
if (n == 10) {
    i = 10;
}
```

2. If there are several levels of indentation, indent each with the same number of spaces. Indent a program using the command Tools->Indent in ChIDE with four spaces for each level of indentation.

5.5. Chapter Summary

```

/* File: grosspay.ch
Calculate the gross pay, deducted tax, and net pay.
Plot the gross pay versus time.
The formula for the gross pay depends on
if(0 <= t <= 8)
    grosspay = 20t
else if (8 <= t <= 24)
    grosspay = 30*t - 80 */
#include <chplot.h>
/* declare variables */
double t, grosspay, netpay, tax;
CPlot plot;

/* get the user input for the hours worked */
printf("Welcome to the Wage Calculator\n");
printf("Please enter the hours worked\n");
scanf("%lf", &t);

/* process the payment */
if(0 <= t && t <= 8) {      /* when 0 <= t <= 8 */
    grosspay = 20*t;
}
else if(8 < t && t <= 24) { /* when 8 < t <= 24 */
    grosspay = 30*t - 80;
}
else {                      /* when t<0 or t > 24 */
    printf("Invalid time\n");
    exit(-1);
}

tax = 0.3*grosspay;
netpay = grosspay - tax;

/* display the payment as output */
printf("    gross pay: %.2lf\n", grosspay);
printf("deducted tax: %.2lf\n", tax);
printf("    net pay: %.2lf\n", netpay);

/* plot the relation of gross pay versus time */
plot.title("Gross pay versus time");
plot.label(PLOT_AXIS_X, "time (hours)");
plot.label(PLOT_AXIS_Y, "gross pay (dollars)");
plot.line(0, 0, 8, 20*8);
plot.line(8, 30*8-80, 24, 30*24-80);

/* plot the point with the user input worked hour and gross pay */
plot.point(t, grosspay);

plot.plotting();

```

Program 5.5: Calculating the wage using **if-else if-else** structure.

5.5. Chapter Summary

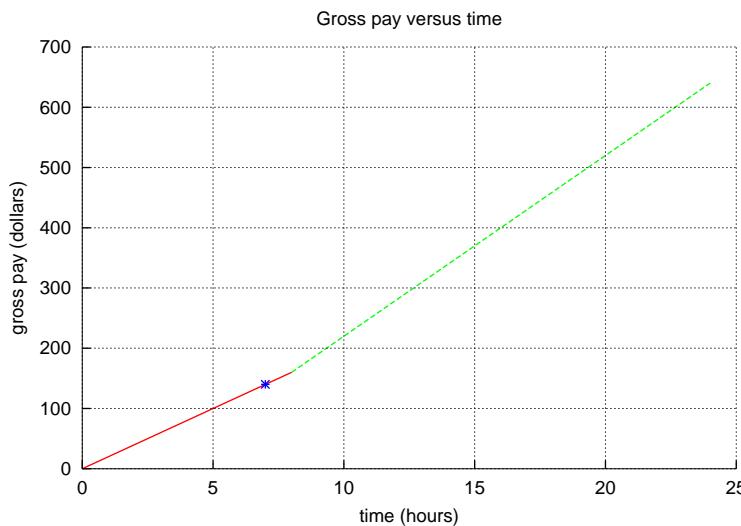


Figure 5.1: The relation between the hours worked and gross pay.

3. Do not insert a space next to a parenthesis. For example, use

```
if(x > 0) {
    printf("x is positive\n");
}
```

instead of

```
if( x > 0 ) {
    printf( "x is positive\n" );
}
```

Common Programming Errors

1. Use the assignment operator = instead of the equality operator ==. For example,

```
if(x = 10) { // bad
    printf("x is 10\n");
}
```

```
if(x == 10) { // good
    printf("x is 10\n");
}
```

2. Forget to brace the compound statement for the body of a selection or repetition statement. For example,

```
if(x > 0) // bad
    printf("x is positive\n");
    x = x + 10;
else
```

5.5. Chapter Summary

```

printf("x is negative\n");

if(x > 0) {                                // good
    printf("x is positive\n");
    x = x + 10;
}
else {
    printf("x is negative\n");
}

```

3. Add a semicolon after the controlling expression for an **if** statement.

```

if(i<n);                                // bad
{
    printf("This is always printed\n");
}

if(i<n)                                // good
{
    printf("This is always printed\n");
}

```

4. Indent the body statements of selection and repetition statements improperly. For example,

```

if(x == 10)                                // bad
{
    x = x + y;
    y = 100;
}

if(x == 10)                                // good
{
    x = x + y;
    y = 100;
}

```

5. Translate mathematical expressions into logical expressions incorrectly. For example,

```

if(0 <= x <= 10) {
    printf("0 <= x <= 10 is true\n");
}

```

should be changed to

```

if(0 <= x && x <= 10) {
    printf("0 <= x <= 10 is true\n");
}

```

6. Separate operators with two adjacent symbols such as `==`, `!=`, `>=`, `<=` with a space.

5.6. Exercises

5.5.2 Terminology**General Concepts**

algorithm	else if statement	false
if statement	if-else statement	logical AND operator
logical OR operator	logical operators	relational operators
selection statements	statement	true

Ch Reserved Words

> greater than operator	>= greater than or equal to operator	!= inequality operator
< less than operator	<= less than or equal to operator	logical inclusive OR operator
== equal-to operator	&& logical AND operator	else
exit()	if	

ChIDE Related Concepts

Tools->Indent

5.6 Exercises

1. Declare two integers *i* and *j* in a Ch Command Shell. Assign *i* with 4 and *j* with 6. Compare these two integers using the relational operators <, <=, ==, >=, >, != in the Ch Command Shell.
2. Write a program *modulus.ch* that reads an integer and determines and prints whether it is odd or even. (Hint: Use the modulus operator %. An even number is a multiple of two. Any multiple of two leaves a remainder of zero when divided by 2. If *n* is an even number, the result *n*%2 is zero.)
3. Identify and correct errors in each of the following code blocks. (Note: there may be more than one error):
 - (a)

```
if(age >= 65);
    printf("Age is greater than or equal to 65\n");
else
    printf("Age is less than 65\n")
```
 - (b)

```
if(i = 2) {
    printf("i is 2\n");
}
else {
    printf("i is not equal to 2\n");
}
```

4. (a) Write a program *rental2.ch* for a Video Rental Shop to process the rental of movies with the user input for the number of movies to be rented. The price for renting a movie is \$3.99. If a customer rents three or more movies, the price is \$3.49 per movie. The sales tax is 8.5 percent. The algorithm for the program is shown below.

```
if(num >= 3) {
    price is 3.49
}
else {
    price is 3.99
```

5.6. Exercises

```
}
```

subtotal = num*price
tax = 0.085*subtotal
total = subtotal+tax

- (b) Use the command Step in ChIDE to run the program `rental2.ch` in the debug mode.

(c) Indent your program with four blank character spaces for each indentation using ChIDE by clicking the command Tools->Indent on the toolbar.

5. State whether the following is true/false. If false, briefly explain why.

(a) The expression `(x<5 && a>b)` is true if either `x<5` or `a>b` is true.

(b) The expression `(x<5 || a>b)` is true if only both `x<5` and `a>b` are true.

6. Based on the program `inspire.ch` developed in Exercise 7 on page 32, write a program `inspire2.ch` to inspire your fellow students to be successful in their future career. When the program is executed, it shall have the following conversation. The contents inside a pair of bracket `[]` are from the user at the prompt. The contents inside a pair of braces `{ }` are replacement of the input from the user.

What is your name?
[John Doe]
Hello {John Doe},
I enjoy computing, what type of hobbies do you like?
[Robotics]
{Robotics} sounds really fun.
Which school do you currently attend?
[Davis Junior High]
{Davis Junior High} is a great school.
[[If the school is your school, print the line below]]
{Davis Junior High} has a fantastic course on computer programming!
What would you like to do in the future?
[scientist]
You should definitely try and be a {scientist}.
Good Luck!

7. Algebra II or Trigonometry is the prerequisite to take Statistics. Write a program `prereq.ch` to ask a student if they have taken Algebra II and assign their answer to a variable. Also ask them if they have taken Trigonometry and assign their answer to another variable. Then check to see if they have the required prerequisite to take the class.

8. Enclose the following C expressions in parentheses the way a compiler or interpreter would evaluate them.

- (a) $a = b + c$ (d) $a = b \&& 2 + 4$
 (b) $a == b || c == d$ (e) $a == b \&& x != y$
 (c) $a == b \&& c > d$ (f) $a == b || x != y$

9. Modify the program `drivertest.ch` in Program 5.1 as the program `drivertest2.ch`. It is assumed that a person in the age between 16 and 78 years old is eligible to obtain a driver license. If a person is 79 years old, he/she needs to pass a mandatory vision test. The program should let the user to enter his/her name and age. The program will print out the following message when a person's age is 79 years or older.

Name, you will need to pass a mandatory vision exam to get a license.

10. The price for one copy of a software package is \$399. The discount for the software depends on the volume as shown in a table below:

5.6. Exercises

Number of copies	Discount
num < 5	no discount
num < 20	10%
num < 50	15%
num \geq 50	20%

Write a program `sale.ch` to calculate the cost with the number of copies of the software package provided by the user at the prompt. What are the costs when the number of copies purchased is 20 and 25?

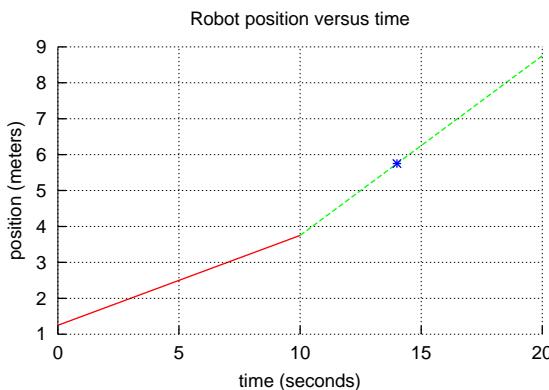
11. The table below is listed in *U.S. Internal Revenue Service 2008 Tax Table* for calculating the tax for a family with a married couple. The taxable income means the gross income minus whatever deductions, such as child support and mortgage, are allowed by the IRS. Write a program `tax.ch` to calculate the tax paid to the IRS based on the user input of the taxable income.

If your taxable income is:	Over—	But not over—	The tax is:	of the amount over—
	\$0	\$16,050 10%	\$0
	16,050	65,100	\$1,605.00 + 15%	16,050
	65,100	131,450	8,962.50 + 25%	65,100
	131,450	200,300	25,550.00 + 28%	131,450
	200,300	357,700	44,828.00 + 33%	200,300
	357,700	96,770.00 + 35%	357,700

12. The initial position of a robot is 1.25 meters. The position of this robot can be expressed as follows:

$$p(t) = \begin{cases} 0.25t + 1.25 & \text{if } 0 \leq t \leq 10 \\ 0.5(t - 10) + 3.75 & \text{if } t > 10 \end{cases}$$

where p is measured in meters from the origin and t is time in seconds. Write a program `robotpos3.ch` to calculate the robot position based on the user input of the time. The program also plots the robot position versus time from 0 to 20 seconds and creates a point at the coordinates for the user input time and the robot position. For example, if the user input time is 14 seconds, the program should display the plot as shown in the illustration below.



CHAPTER 6

Loops for Repetition and Random Numbers

In the previous chapter, we learned how to write a program that makes decisions based on results of relational and logical operations in selection statements. For complicated problems, they may require that an action be repeated a number of times. Repeating actions can be accomplished using *repetition* or *iteration statements*, which are executed until a condition is no longer true. Incorporating the selection and repetition statements in programs is called *structured programming*. In this chapter, we will learn two types of repetition statements: **while** loops and **for** loops. We will also learn how to generate random numbers.

6.1 The **while** Loop

Prerequisite: Understanding variable types, program structure, arithmetic and relational operators

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4, RST.6-12.7

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1

Objective: Use repetition **while** statements to control how many times a series of statements are executed.

The syntax of a **while** statement is as follows:

```
while(expression) {  
    statement;  
}
```

6.2. Debugging Programs with Repetition Statements Using ChIDE

```
/* File: oddnum.ch
   print odd numbers from 1 to 11 using a while-loop. */

int i;           // declare i
int n = 11;      // declare n and initialize the largest odd number 11

i = 1;           // initialize the variable i
while(i <= n) { // when i <= 11
    printf("%d ", i);
    i = i + 2;  // give the next odd number
}
printf("\n");    // print a newline character
```

Program 6.1: Printing odd numbers from 1 to 11 using a **while** loop.

The evaluation of the controlling expression takes place before each execution of the loop body. The loop body is executed repeatedly until the controlling expression returns a false value.

Example The following code

```
int i = 0;
while(i<5) {
    printf("%d ", i);
    i = i + 1;
}
printf("i after the while loop is %d ", i);
```

will output

```
0 1 2 3 4
i after the while loop is 5
```

6.2 Debugging Programs with Repetition Statements Using ChIDE

As a repetition statement is executed you can use your debug pane to watch the index value change with each iteration and compare it to the terminating expression. This can be very helpful when debugging loops. As an example, open the program `oddnum.ch` in Program 6.1 in ChIDE and click the command Step repeatedly until the program terminates. Watch the variables change values in the debug pane. The program prints odd numbers from 1 to 11 as shown below.

```
1 3 5 7 9 11
```

The variable `i` in Program 6.1 contains odd numbers. It is first initialized with the value 1. At each iteration in the **while** loop, the statement

```
i = i + 2; // gives the next odd number
```

gives `i` the next odd number. The body of the loop is executed until the condition $i \leq n$ is false.

 Do Exercises 1 and 2 on page 107.

6.3 Increment and Decrement Operators

Prerequisite: Understanding variable types, program structure, and arithmetic operators

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D4.1

Objective: Use increment and decrement operators to add or subtract values from/to a variable.

C is well-known for being short, clear, and precise. The increment operator `++` adds 1 to its operand. The expression `i++` is equivalent to `i = i+1`. The decrement operator `--` subtracts 1 from its operand. The expression `i--` is equivalent to `i = i-1`. For example,

```
> int i = 1
> i++
1
> i
2
> i++
2
> i
3
```

Using the increment operator `++`, the previous **while** loop

```
int i = 0;
while(i<5) {
    printf("%d ", i);
    i = i + 1;
}
```

can be written as

```
int i = 0;
while(i<5) {
    printf("%d ", i);
    i++;
}
```

④ Do Exercise 3 on page 107.

6.4 Control of Repetition

6.4.1 Counter-Controlled Repetition

As described in section 2.3 and shown in Program 2.2 in Chapter 2, a structured program in C typically consists of four sections, namely, *declaration*, *initialization*, *processing*, and *termination*.

As another example, consider the following problem statement.

6.4. Control of Repetition

```

/* File: gpa.ch
   Calculate the GPA for NUM grades entered from the terminal */

/* number of grades entered from the terminal */
#define NUM 4

/* declaration */
int count;
double grade, total, gpa;

/* initialization */
count = 0;
total = 0;

/* processing input grades and calculate the GPA */
while(count < NUM) {
    printf("Enter a grade:\n");
    scanf("%lf", &grade);
    total = total + grade;
    count++;
}
gpa = total/NUM;

/* display output and termination */
printf("The GPA is: %lf\n", gpa);

```

Program 6.2: Calculating the GPA with grades for four courses.

A student takes four courses in a quarter. Each course will be assigned a grade with the score from 0 to 4. Develop a C program to calculate the grade point average (GPA) for the quarter.

The algorithm for this problem needs to first input grades. Then, save the grade for each class to a variable for the total points. Next, calculate the GPA, which is the sum of the grades divided by the number of classes taken. Finally, print the GPA.

Program 6.2 is the implementation of an algorithm. Program 6.2 also contains the four phases of *declaration*, *initialization*, *processing*, and *termination*. Sometimes it is useful to set a constant in a program so that it can be easily changed. This is called a *macro*. The total number of classes taken is fixed in this program. Therefore, it is defined as a macro NUM in the following statement.

```
#define NUM 4
```

The variable `count` of `int` type is used to count the number of grades entered. The grade for each class is entered and saved in the variable `grade` of `double` type because it is a decimal number. The variable `total` of `double` type for a floating point number is used to accumulate the sum of a series of grades which are decimal numbers. The variables `total` and `count` are initialized. To obtain a GPA with significant digits after a decimal point, the variable `gpa` of `double` type is also used. The division of two variables `total` and `count`, one in `double` and the other in `int`, results in a floating point value of `double` type. A sample execution of Program 6.2 is given below.

```

> gpa.ch
Enter a grade:
4
Enter a grade:
3.7

```

6.4. Control of Repetition

```
Enter a grade:  
3.3  
Enter a grade:  
4  
The GPA is: 3.750000
```

In Program 6.2, the repetition is controlled by a counter. In this **counter-controlled repetition**, an integer variable count in the controlling expression of the **while** loop

```
while (count < NUM)
```

in Program 6.2, is used to specify the number of times a set of statements inside a loop should be executed. In Program 6.2, the repetition ends when the counter equals NUM, defined as 4. In this counter-controlled repetition, there are definite repetitions. The number of repetitions is known in advance before the loop begins execution.

 Do Exercises 4 and 5 on page 107.

As another example, Program 6.3 uses a **while** loop below to plot multiple circles as shown in Figure 6.1.

```
r = 1;  
while (r<=3) {  
    plot.circle(centerx, centery, r);  
    r++;  
}
```

The radius for the first circle is 1. At each iteration, the radius increments up by 1. The radius for the last one is 3, determined by the loop control expression $r \leq 3$.

```
/* File: circles.ch  
Draw circles centered at (0, 0).  
The radius for the first circle is 1. At each iteration,  
the radius increments 1. The radius for the last one is 3. */  
#include <chplot.h> /* for CPlot */  
CPlot plot;  
double centerx = 0, centery = 0, r;  
  
plot.sizeRatio(1); // set the plot size ratio for appearance of circles  
  
/* draw circles */  
r = 1;  
while (r<=3) {  
    plot.circle(centerx, centery, r);  
    r++;  
}  
  
/* draw a point at the center of circles */  
plot.point(centerx, centery);  
  
plot.plotting();
```

Program 6.3: Plotting multiple circles using a **while** loop.

6.4. Control of Repetition

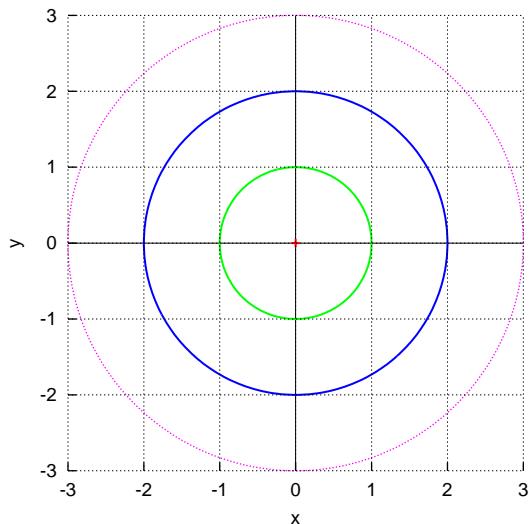


Figure 6.1: Circles generated by Program 6.3.

Do Exercise 6 on page 108.

6.4.2 Sentinel-Controlled Repetition

In some applications, the number of repetition might not be known in advance. For example, consider the following problem statement.

Application: Processing Multiple Orders in a Lemonade Shop

Write a program for a Lemonade Shop to process multiple orders for lemonade. The sale price for lemonade is \$0.39 per ounce. The sales tax is 8.25 percent.

In this example, the number of orders for buying lemonade is not known. The program needs to process multiple orders. How can the program determine when to stop inputting orders?

To solve this problem, a special value called a **sentinel value** or **signal value** can be used to indicate the continuation or end of data entry. In this example, the user enters the word `yes` to continue. The sentinel value should be carefully chosen so that it will not be confused with the acceptable input value.

6.4. Control of Repetition

```

/* File: lemonade3.ch
   Calculate the cost with sales tax for a Lemonade Shop
   with multiple orders */

/* declare variables */
int cups;
double price, taxrate, subtotal, tax, total;
string_t answer = "yes"; /* "yes" to continue, others to quit */

/* fixed price and tax rate */
price = 1.29;           // $1.29 per cup
taxrate = 0.0825;        // 8.25% (8.25 percent) sales tax

/* get the user input for the value of the variable cups */
/* '%' will print out one '%' */
printf("Welcome to Mary's Lemonade Shop\n");
printf("We sell lemonade by the cup, $1.29 per cup with 8.25% sales tax.\n");
while (answer == "yes") {
    printf("Please enter the number of cups.\n");
    scanf("%d", &cups);

    /* process the order */
    subtotal = price * cups;      // cost before tax
    tax = taxrate * subtotal;     // sales tax
    total = subtotal + tax;       // total cost with tax

    /* display the cost as output */
    printf("Subtotal: $%.2lf\n", subtotal);
    printf("    Tax: $%.2lf\n", tax);
    printf("    Total: $%.2lf\n", total);
    printf("Thank you.\n\n");

    printf("Would you like to order more lemonade? Type yes or no.\n");
    scanf("%s", &answer);
}
printf("\nThank you for shopping, have a nice day!\n\n");

```

Program 6.4: A program for processing multiple orders for a Lemonade Shop.

Program 6.4 can be used to process multiple orders for lemonade. Its user interface is shown below for a sample execution of the program.

```

Welcome to Mary's Lemonade Shop
We sell lemonade by cups, $1.29 per cup with 8.25% sales tax.

Please enter the number of cups.
3
Subtotal: $3.87
    Tax: $0.32
    Total: $4.19
Thank you.

Would you like to order more lemonade? Type yes or no.
yes
Please enter the number of cups.
4

```

6.5. The **for** Loop

```

Subtotal: $5.16
    Tax: $0.43
    Total: $5.59
Thank you.

Would you like to order more lemonade? Type yes or no.
no
Thank you for shopping, have a nice day!

```

In this case, the program first processes an order with 3 cups of lemonade. The next order is 4 cups. Then, it quits. Similar to Program 2.5 in Chapter 2 for a single order for lemonade. The program first asks the user to enter the number of cups of lemonade to be purchased. The breakdown and total costs are then displayed. Next, the user is asked to enter either *yes* for the next order or *no* to quit the program. If the user input is *yes*, the program processes the order repeatedly. In Program 6.4, the repetition is handled by a **while** loop. If the value of the variable *answer* of string type is *yes*, the conditional expression of the **while** loop

```
answer == "yes"
```

is true and the program will continue to process a new order. If the user input is *Yes*, the program will terminate. In order to accept both *yes* and *Yes* for continuing the order, the condition expression of the **while** loop should be modified with a logical OR operation as follows.

```
while(answer == "yes" || answer == "Yes")
```

The statement

```
scanf("%d", &cups);
```

assigns a value to the variable *cups*. After the output statement

```
printf("Would like to order more lemonade? Type y for yes.\n");
```

the user enters *yes*.

The statement below assigns the user input *yes* to the variable *answer*.

```
scanf("%s", &answer);
```

 Do Exercise 7, 8, 9, and 10 on page 108.

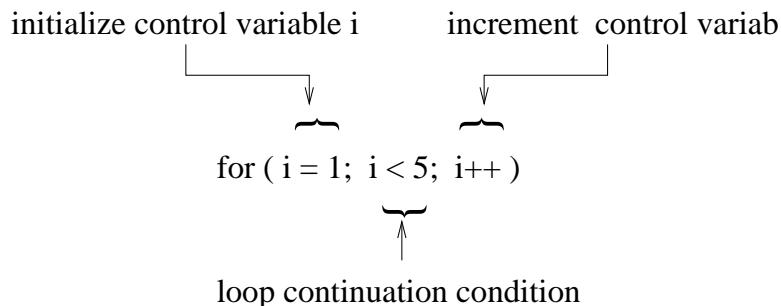
 Do Exercise 11, on page 108.

6.5 The **for** Loop

The syntax of a **for** statement is as follows:

```
for(expression1; expression2; expression3) {
    statement;
}
```

For a **for** loop, after *expression1* is evaluated, the program evaluates *expression2*, and if *expression2* is true, the statement is executed and *expression3* is evaluated. The **for** loop continues until *expression2* is no longer true.

6.5. The **for** LoopFigure 6.2: A typical **for** loop construct.

The **for** loop is semantically equivalent to the following **while** loop

```
expression1;
while(expression2) {
    statement;
    expression3;
}
```

As illustrated by the code fragment below,

```
int i;
for(i=0; i<5; i++) {
    printf("%d ", i);
}
```

a **for** loop is initialized and controlled according to the format in Figure 6.2. The first expression `i=0` initializes the loop control variable `i` with 0. The second expression `i<5` is the loop continuation condition. The loop iterates when the control variable `i` is less than 5. The third expression `i++` increments the control variable after the loop body

```
printf("%d ", i);
```

is executed. The above code fragment will produce the same output of

```
0 1 2 3 4
```

as in a **while** loop of

```
int i = 0;
while(i<5) {
    printf("%d ", i);
    i++;
}
```

as described in section 6.1. Similarly, the program `oddnum.ch` in Program 6.1 can be re-written using a **for** loop as shown in the program `oddnum2.ch` in Program 6.5. Both programs produce the same output. You can run the program `oddnum2.ch` in ChIDE using the command Step to see how variables change as the program is executed step-by-step.

Do Exercises 12, 13, and 14 on page 109.

As another example, Program 6.6 uses a **for** loop below to plot multiple squares as shown in Figure 6.3.

```
for(length=2; length<= 6; length=length+2) {
    plot.rectangle(x, y, length, length);
    x--;
    y--;
}
```

6.6. Formatting Output with a Specified Field Width

```
/* File: oddnum2.ch
   print odd numbers from 1 to 11 using a for-loop. */

int i;           // declare i
int n = 11;      // declare n and initialize the largest odd number 11

for(i = 1; i <= n; i = i+2) {
    printf("%d ", i);
}
printf("\n");    // print a newline character
```

Program 6.5: Printing odd numbers from 1 to 11 using a **for** loop.

```
/* File: squares.ch
Draw squares. The lower left corner of the first square is at (-1, -1),
At each iteration, the x and y coordinates decrement 1,
and the size length increases by 2.
The last one will be at (-3, -3) with the size length 6. */
#include <chplot.h> // for CPlot

CPlot plot;
double x = -1, y = -1, length;

plot.sizeRatio(1); // set the plot size ratio for appearance of squares

/* draw squares */
for(length=2; length<= 6; length=length+2) {
    plot.rectangle(x, y, length, length);
    x--;
    y--;
}

plot.plotting();
```

Program 6.6: Plotting multiple squares using a **for** loop.

The lower left corner of the first square with the size length 2 is located at (-1, -1), At each iteration, the x and y coordinates of the lower left corner of the new square decrement 1 whereas the side length increases by 2. The size length for the last squares is 6, determined by the loop control expression `length<=6`.

 Do Exercises 15, 16, and 17 on page 109.

6.6 Formatting Output with a Specified Field Width

In section 2.2.1, we learned how to format output with precision for decimal numbers using the function `printf()`. In some applications, we may need to specify the field width in the output. The **field width** is considered to be the size of a field in which data are printed. If the number has fewer characters than the field width, then it is padded with space on the left (right-justified) to match the field width. If the field width is too small, it is automatically increased to fit the data. An integer width may be inserted between % and the conversion specifier to indicate a field width. For example, `%6d` specifies a field width of 6 for an integer. `%8.4f` specifies a field width of 8 with 4 digits after the decimal point, as shown below.

```
> printf("%lf", 5.12345) // no field width is specified.
```

6.6. Formatting Output with a Specified Field Width

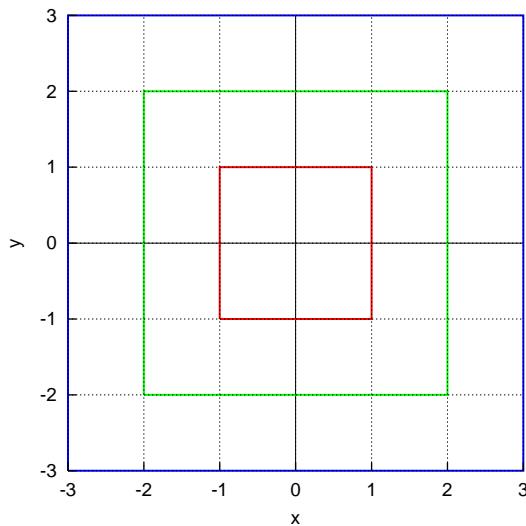


Figure 6.3: Squares generated by Program 6.6.

```

5.123450
> printf("%.4lf", 5.12345) // 4 digits after the decimal point
5.1235
> printf("%8.4lf", 5.12345) // field width of 8
      5.1235
> printf("%d", 12)          // no field width specified
12
> printf("%6d", 12)          // field width of 6
      12

```

The field width will be used in an application example in this section.

Iterative statements are useful for numerical computations. In general, to evaluate an equation linearly from x_0 to xf with a step size of $xstep$, we can use a **for** loop as follows.

```

for(x=x0; x<= xf; x = x+xstep) {
    statement;
}

```

Application: Creating a Temperature Conversion Table

Problem Statement:

The relation between the temperature in Fahrenheit and Celsius degrees can be expressed in the following mathematical formula:

$$y = \frac{5(x - 32)}{9} \quad (6.1)$$

where y is the temperature in Celsius and x in Fahrenheit. Creating a temperature conversion table between these two units for temperature in Celsius for x from 0 to 120 with a step size of 10

6.6. Formatting Output with a Specified Field Width

```

/* File: celsius.ch
   Transfer the temperature from Fahrenheit to Celsius
   for x from 0 to 120 with step size 10 */

double x, x0, xf, xstep, y;

printf("Fahrenheit  Celsius\n");
printf("-----\n");
x0 = 0.0;                                // initial value for x
xf = 120.0;                               // final value for x
xstep = 10.0;                             // step size for x
for(x = x0; x <= xf; x = x+xstep) {
    y = 5*(x - 32)/9;
    printf("%5.1f %12.2lf\n", x, y); // display the result
}

```

Program 6.7: Printing a temperature conversion table from Fahrenheit to Celsius using equation (6.1).

Fahrenheit	Celsius
0	-17.78
10	-12.22
20	-6.67
30	-1.11
40	4.44
50	10.00
60	15.56
70	21.11
80	26.67
90	32.22
100	37.78
110	43.33
120	48.89

Figure 6.4: The output from Programs 6.7 and 7.3 in Chapter 7.

Based on equation (6.1), Program 6.7 can be used to create the temperature conversion table shown in Figure 6.4. To calculate equation (6.1) for x in the range of $0 \leq x \leq 120$ with a step size of 10, a **for** loop is used in Program 6.7. The initial value `x0`, final value `xf`, and step size `xstep` are 0, 120, and 10, respectively. At the end of each iteration inside the **for** loop in Program 6.7, values for the variable `x` are printed using the conversion specifier `%5.1f`, which specifies a field width of 5 and ignores the values after the decimal point. For the values of the variable `y`, the conversion specifier `%12.2lf` specifies a field width of 12 with two digits after the decimal point.

 Do Exercise 18 and 19 on page 110.

6.7. The **break** Statement

6.7 The **break** Statement

Prerequisite: Understanding variable types, program structure, arithmetic and relational operators, looping

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1

Objective: Apply the C statement **break** to exit early from **for** and **while** loops.

The **break** statement provides an early exit from **for** and **while** loops. A break causes the innermost loop to be exited immediately. A **break** statement shall appear only in a loop body. For example, the following code fragment

```
int i;
for(i=0; i<5; i++) {
    if(i == 3) {
        break;
    }
    printf("%d \n", i);
}
```

will produce the output of

0 1 2

6.8 Random Number Generation

Prerequisite: Understanding variable types, program structure, arithmetic and relational operators, looping

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1

Objective: Use the C functions **randint()** to generate pseudo-random numbers to simulate the roll of a die or flip of a coin.

Random numbers are commonly used in game, simulation, and statistical analysis. A random number in the range of $[a, b]$ can be conveniently generated by the function call **randint(a, b)** as follows.

```
n = randint(a, b);
```

An interactive execution of the function **randint()** in a Ch command shell is shown below.

```
> randint(1, 10)      // generate a random number between 1 to 10
4
> randint(1, 100)     // generate a random number between 1 to 100
67
```

6.8. Random Number Generation

Typically, the range of numbers from `randint()` is different from the desired range for a given application. For example, the flipping of a coin only requires 0 for "heads" and 1 for "tails". Thus, integers ranging from 0 to 1 are desired for simulating a coin toss by calling the random function `randint(0, 1)`. Similarly, the rolling a six-sided die would require an integer ranging between 1 and 6 by calling the random function `randint(1, 6)`.

 Do Exercises 20, 21, and 22 on page 110.

Application: Testing the Result for Addition of Two Random Numbers

Problem Statement:

Write a program `addtest.ch` to generate two random integers ranging from 1 to 10 using the function `randint()`. Then prompt the user to enter the sum of the two numbers. If the user enters the correct answer, print "Correct!". If it is wrong, print "Incorrect. Please try again." and allow the user to enter another answer until it is right.

```
/* File: addtest.ch
   Test the result for addition of two numbers in the range [1, 10] */

int x, y, answer;      /* two random numbers and the user input answer */

x = randint(1, 10);    /* get x in the range [1, 10] */
y = randint(1, 10);    /* get y in the range [1, 10] */

printf("What is %d + %d? ", x, y);
scanf("%d", &answer); /* get the user's answer */

/* while the user's answer is incorrect, continue to get the answer */
while(answer != (x + y)) {
    printf("Incorrect. Please try again.\n");
    printf("What is %d + %d? ", x, y);
    scanf("%d", &answer);
}

printf("Correct!\n");  /* the answer must be correct to reach */
```

Program 6.8: A program to test the result for addition of two random numbers.

Program 6.8 is an example that encapsulates all the above aspects discussed for random number generation. Program 6.8 can be used to test the result for addition of two random numbers. Two variables `x` and `y` are assigned two random numbers ranging from 1 to 10. The user input for the answer of these two random numbers is stored in the variable `answer`. The condition expression of the `while` loop tests if the answer is correct. If the condition expression is false, statements inside the `while` loop are executed to display messages for the user to input a new answer. The `while` loop will be iterated until the input answer is correct. At the end, the message `Correct!` is displayed. A sample execution of Program 6.8 is shown below:

What is 3 + 2? 6

6.8. Random Number Generation

```
Incorrect. Please try again.  
What is 3 + 2? 7  
Incorrect. Please try again.  
What is 3 + 2? 5  
Correct!
```

 Do Exercises 23, 24, 25, and 26 on page 111.

Application: Rolling a Six-Sided Die

Program 6.9 simulates the rolling of a six-sided die 6,000 times. If the program is truly random, then each number between 1 and 6 will have an equal likelihood of occurring. The frequency of each occurrence is displayed at the end of program execution. Program 6.9 first initializes the counters freq1, freq2, ..., freq5 for recording the frequency of occurrence for each integer. A **for** loop is then used to “roll” the die 6,000 times, and the counter trial is incremented accordingly. An **if-else if-else** statement is used to record the occurrence for one of six faces in each roll in a frequency variable for that face.

6.8. Random Number Generation

```

/* File: srand.ch
   Roll a six-sided die 6,000 times randomly,
   calculate the frequency for each face. */

int face,          /* face in each roll*/
    trial,          /* roll count number */
    freq1 = 0, freq2 = 0, freq3 = 0, /* frequency for each face */
    freq4 = 0, freq5 = 0, freq6 = 0;

/* use a loop to roll 6,000 times */
for (trial = 1; trial <= 6000; trial++) {
    face = randint(1, 6); /* generate a random number in [1, 6] */
    /* record the face in a frequency variable */
    if (face == 1) { /* if face is 1 */
        freq1++; /* increment the frequency variable for face 1 */
    }
    else if (face == 2) { /* if face is 2 */
        freq2++; /* increment the frequency variable for face 2 */
    }
    else if (face == 3) {
        freq3++;
    }
    else if (face == 4) {
        freq4++;
    }
    else if (face == 5) {
        freq5++;
    }
    else { /* if (face == 6) */
        freq6++;
    }
}

/* display the frequency for each face */
printf(" Face      Frequency\n");
printf(" 1          %d\n", freq1);
printf(" 2          %d\n", freq2);
printf(" 3          %d\n", freq3);
printf(" 4          %d\n", freq4);
printf(" 5          %d\n", freq5);
printf(" 6          %d\n", freq6);

```

Program 6.9: Rolling a six-sided die 6,000 times.

The output of Program 6.9 is shown below. Notice that occurrence of each face is relatively the same.

Face	Frequency
1	1003
2	994
3	996
4	1021
5	990
6	996

 Do Exercises 27 and 29 on page 112

6.8. Random Number Generation

Random floating-point values in a specified range are needed for probability and statistics analysis. A random floating-point value in the range of $[a, b]$ can be conveniently generated by the function call **randdouble(a, b)** as follows.

```
x = randdouble(a, b);
```

The function **randdouble()** returns a random value of **double** type. The function **randdouble()** can be used in the same manner as the function **randint()**. An interactive execution of the function **randdouble()** in a Ch Command Shell is shown below.

```
> randdouble(-1, 1)      // generate a random value between -1 and 1  
-0.5434  
> randdouble(-1, 1)      // generate a random value between -1 and 1  
0.9437  
> randdouble(0, 1)       // generate a random value between 0 and 1  
0.3745
```

 Do Exercises 28 and 29 on page 112.

6.9 Chapter Summary

6.9.1 Programming Tips

Good Programming Practice

1. Indent the body of repetition statements. For example,

```
while(i <= n) {
    printf("i = %d\n", i);
    i++;
}
```

2. If there are several levels of indentation, indent each with the same number of spaces. Indent a program using the command Tools->Indent in ChIDE with four spaces for each level of indentation.
3. In a sentinel-value controlled repetition, the prompt for the user input should display the sentinel value.
4. Use only capital letters for macros. For a multi-word macros, use underscore to separate the words. For example,

```
#define N          10
#define BLOCK_SIZE 1024
```

Common Programming Errors

1. Add a semicolon after the controlling expression for a **while** loop.

```
while(i <= n);           // bad.
{
    printf("This is printed once only\n");
    i++;
}

while(i <= n)           // good
{
    printf("This is printed once only\n");
    i++;
}
```

2. Add a semicolon after the controlling expression for a **for** loop.

```
for(i=0; i<=n; i++);           // bad
{
    printf("This is printed once only\n");
}

for(i=0; i<=n; i++)           // good
```

6.10. Exercises

```
{
    printf("This is printed once only\n");
}
```

3. Use a sentinel value that is also a legitimate data value.
4. Use lowercase letters for a macro for a constant. For example,

```
#define blockSize 1024           // bad
#define BLOCKSIZE 1024          // good
```

6.9.2 Terminology**General Concepts**

counter-controlled repetition	for loop	iteration statement
macro	loop	repetition statement
sentinel value	sentinel-controlled repetition	structured programming
while loop		

Ch Reserved Words

#define	break	for
randint()	randdouble()	while

6.10 Exercises

1. Identify and correct errors in each of the following code blocks.

```
(a) int i = 0;
    while(i<10);
    {
        printf("i is %d\n", i);
        i = i + 1;
    }
```

2. Write a program `whileloop.ch` using a **while** loop to print the following sequence of even numbers.

2 4 6 8 10 12 14 16

Indent your programs with four blank character spaces for each indentation using ChIDE by clicking the command Tools->Indent on the toolbar.

3. Rewrite the following C statements using increment and decrement operators.

```
int i = 10;
i = i + 1;
i = i - 1;
```

Verify the results in a Ch Command Shell.

4. It is important to write an efficient program with a correct algorithm. Write a program `loop3.ch` using a **while** loop to add integers from 1 to n with n equal to 1,000. Verify the result using the formula $n(n + 1)/2$ for the sum from 1 to n , which is more efficient than using a loop.

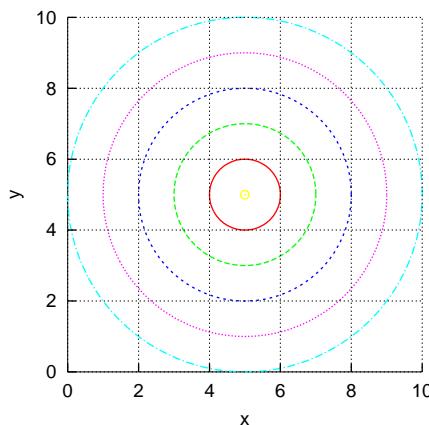
6.10. Exercises

5. Write a program `average3.ch` that calculates and prints the average of several integers. Assume that the last value read with `scanf()` is sentinel number 9999. A typical input sequence might be

```
10 8 11 7 9 9999
```

indicating that the average of all the values preceding 9999 is to be calculated.

6. Write a program `circles2.ch` using a `while` loop to plot circles as shown in the figure below.



7. For the Video Rental Shop described in Exercise 4 in Chapter 5, write a program `rentals.ch` to process multiple orders for renting movies.
8. For the Ice Cream Shop described in Exercise 9 in Chapter 2, write a program `icecreams.ch` to process multiple ice cream orders.
9. For the Picture Frames Shop described in Exercise 5 in Chapter 3, write a program `frames.ch` to process multiple picture frame orders.
10. Write a GPA calculation program `gpa4.ch` that will process grades with scores of 0, 0.7, 1, 1.3, 1.7, 2, 2.3, 2.7, 3, 3.3, 3.7, and 4 only for an arbitrary number of courses. The user shall input a sequence of scores. The program shall check if each input score is valid. Before the program exits, it calculates the GPA based on the previously entered scores. When the user inputs a value of `-1`, the program will terminate. Run your program with the testing scores below.

```
4 3.3 3.0 2.7 1.0 1.3 0.0 0.7 4.0 1.7 5 3.7 -1
```

11. Write a program `relax.ch` to comfort a patient. When the program is executed, it shall have the following conversation. The contents inside a pair of bracket `[]` are from the user at the prompt. The contents inside a pair of braces `{ }` are replacement of the input from the user.

```
Please, relax.  
How are you feeling?  
[very bad]  
Why do you feel {very bad}?  
[I broke my leg]  
Tell me more about "{I broke my leg}."  
[I stepped on a banana and fell on the ground]  
I see.  
Do you want to talk more? Type yes or no.  
no  
  
I hope you feel better now.  
Goodbye!
```

If the user enters `yes`, the programs shall start with the conversation again with the question

6.10. Exercises

How are you feeling?

12. Write a program `loop2.ch` using a **for** loop to print the following sequence of even numbers exactly including commas:

`2, 4, 6, 8, 10, 12, 14, 16`

13. Identify and correct errors in each of the following code blocks.

- (a) The following code should output the odd integers from 999 to 1:

```
int i;
for(i = 0; i<10; i++) {
    printf("%d\n", n);
}
```

- (b) The following code should output the odd integers from 999 to 1:

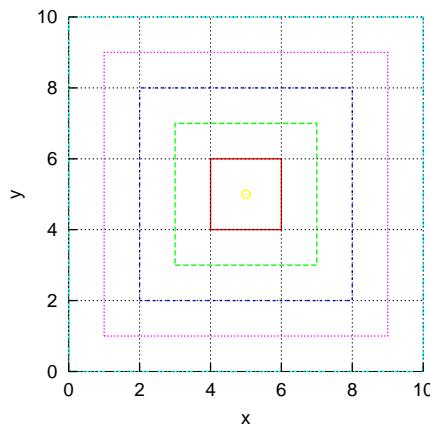
```
for(x = 999; x >= 1; x = x+2) {
    printf("%d\n", n);
}
```

14. Write a program `birthday.c`. It accepts a name entered by the user, then writes the lyrics to the Happy Birthday song using the given name. For example, if the user enters the name John, the program can be executed interactively as follows:

```
Welcome to the Birthday Place
Whose birthday is it?
John
Happy Birthday to you
Happy Birthday to you
Happy Birthday dear John
Happy Birthday to you
```

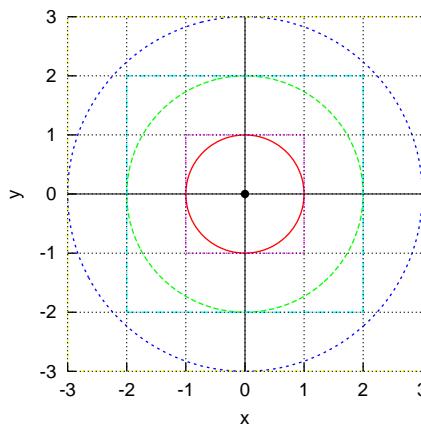
The program should use a **for** loop and **if-else** statements to print out the last four lines.

15. Write a program `squares2.ch` using a **for** loop to plot squares as shown in the figure below.

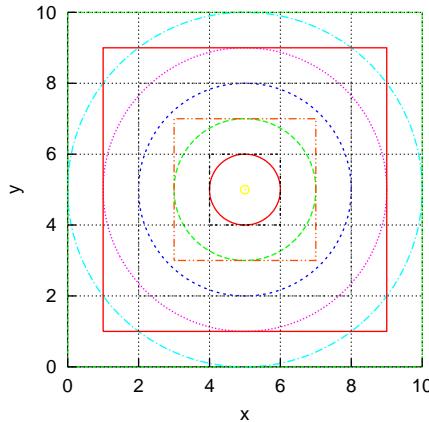


16. Based on Programs 6.3 and 6.6, write a program `circlesquares.ch` using a **for** loop to plot circles and squares as shown in the figure below.

6.10. Exercises



17. Based on programs developed in Exercises 6 and 15, write a program `circlesquares2.ch` using a **for** loop to plot circles and squares as shown in the figure below.



18. Write programs `f1.ch` and `f2.ch` to calculate the values of the following math formulas for x in the range of $-1 \leq x \leq 5$ with a step size of 0.25, and display the output in the format shown in Figure 6.4. Note that $y = 0$ at the x-intercept.

(a) $y = 2x - 4$ (b) $y = -x^2 + 5x - 6$

19. Write a program `interest.ch` to display the total amount of the money with the interest compounded annually from 1 to 30 years. The user enters the principal and rate of interest. The mathematical relationship is as follows,

$$y = p(1 + r)^n$$

where y is the amount, p the principal invested, r the interest rate, and n the number of years. Test your program with the invested principal of \$10,000 and 8% interest rate. The interactive execution of the program shall be as follows.

```
Enter the principal: 10000
Enter the interest rate (%): 8
year    total
1      $10800.00
2      $11664.00
...

```

20. Generate two random numbers in the range of [1, 100] using the function `randint()` in a Ch Command Shell.

6.10. Exercises

21. Write a program `randomint.ch` with the function `randint()` to generate and print 20 random integer numbers in the range [6, 15].
22. Write a C program `guessnum.ch` that uses the function `randint()` to generate an integer randomly in the range of 1 to 50. The program then prompts the user to guess the number by displaying the following messages:

```
I have a number between 1-50.  
Can you guess what it is?  
Enter your initial guess.
```

After the user's initial guess, the program should display one of the following responses:

- (1) Correct! That's the number.
Would you like to play again (y or n)?
- (2) Too low. Guess again.
- (3) Too high. Guess again.

The program should loop until the user guesses the correct answer. Use the "Too low" and "Too high" messages to help the user guess the number. Once the user guesses the right number, the program should ask whether he/she would like to play again.

23. (a) Write a program `randomadda.ch` to generate two random integers ranging from 1 to 10 using the random function `randint()`. Prompt the user to enter the sum of the two numbers. If the user enters the correct answer, print "Correct!". If it is wrong, print "Incorrect. Please try again." and allow the user to enter another answer until it is right.
- (b) Modify Program 6.8 as a program `randomaddb.ch` to ask the user a total of ten addition problems. At the end of the 10th question, print a message to tell the user how many problems were answered correctly. If the user has more than 8 correct solutions, give a complementary comment. For fewer than 6 correct solutions, give an encouragement statement. Note that the user should only have one chance to answer each question. A fragment of the code is shown below.

```
right = 0;  
for(i = 1; i <= 10; i++) {  
    x = randint(1, 10);  
    y = randint(1, 10);  
    printf("(d) What is %d + %d? ", i, x, y);  
    scanf("%d", &response);  
    if(response == (x + y)) {  
        right++;  
    }  
}
```

24. In Exercise 23, two random numbers ranging from 1 to 10 are added. Write programs `randommulta.ch` and `randommultb.ch` to do the same for multiplication of two random numbers ranging from 1 to 10.
25. In Exercise 23, two random numbers ranging from 1 to 10 are added. Write programs `randomsuba.ch` and `randomsubb.ch` to do the same for subtraction of two random numbers ranging from 1 to 100.
26. (a) Write a program `randomaddsub.ch` to generate two random integers ranging from 1 to 10 using the random function `randint()`. A random operation of either addition or subtraction for these two numbers will be selected. Prompt the user to enter the result of the operation. If the user enters the correct answer, print "Correct!". If it is wrong, print "Incorrect!". Ask the user a total of 10 problems. At the end of the 10th question, print a message to tell the user how many problems were answered correctly. If the user has more than 8 correct solutions, give a complementary comment. For fewer than 6 correct solutions, give an encouragement statement. Note that the user should only have one chance to answer each question.
- (b) Modify the program `randomaddsub.ch` as a program `randomaddsubmul.ch` to select a random operation of addition, subtraction, or multiplication.

6.10. Exercises

27. Write a program `flipcoin.ch` to simulate the flipping of a coin 10,000 times and print the simulation result similar to the one shown below.

Coin Face	Frequency
head	4949
tail	5051

Modify the program to change the number of coin flipping from 10,000 times to 100,000 times.

28. Write a program `randomfloat.ch` with the function `randdouble()` to generate and print 20 random floating-point values in the range [-2.0, 2.0].

29. ‡ The *Monte Carlo method*, which evaluates the results of multiple random trials, can be used to create an approximation of π . If a circle of radius r is inscribed inside a square with the side length $2r$, then the area of the circle will be πr^2 and the area of the square will be $(2r)^2 = 4r^2$. So the ratio of the area of the circle to the area of the square will be as follows.

$$\frac{\text{area_of_circle}}{\text{area_of_square}} = \frac{\pi}{4}$$

If points are randomly placed in the square, the ratio of the number of points inside the circle (M) to the total number of points (N) will be approximately the same as the ratio of the area of the circle to the area of the square. That is

$$\frac{M}{N} = \frac{\pi}{4}$$

Therefore, the value of π can be approximated as follows:

$$\pi = 4 \frac{M}{N}$$

Modify Program 4.8 in Chapter 4 to write a program `pi.ch` to draw a square with the side length 2 and a circle with the radius of 1, then place 1,000 (N) points randomly inside the square as shown in Figure 6.5. The program keeps track the number of points inside the circle. Assume x and y are the coordinates of the point. The distance of the point to the origin is $\sqrt{x^2 + y^2}$. If the point is inside the circle with the radius of 1, then the distance of the point to the origin should be less than 1, i.e. $\sqrt{x^2 + y^2} \leq 1$. Use the following algorithm to place N points randomly within the square and count the number of points inside the circle. Then, obtain the approximate value of π .

```

for (trial = 1; trial <= N; trial++) {
    /* Generate a random point in the square (-1<=x<=1, -1<=y<=1) */
    x = randdouble(-1, 1);      // x-coordinate of the random point
    y = randdouble(-1, 1);      // y-coordinate of the random point
    datanum++;                  // increment the data set number
    plot.point(x, y);          // plot this random point
    plot.pointType(datanum, pointType, pointSize, "black");
    if(sqrt(x*x+y*y) < 1) {   // the point is inside the circle
        count_inside++;
    }
}
pi = 4.0*count_inside/N;

```

The program should also print the value of `M_PI`. Please note that the Monte Carlo method for approximating π is very slow compared to other methods. When the computational speed or accuracy is desired, the other method should be used.

6.10. Exercises

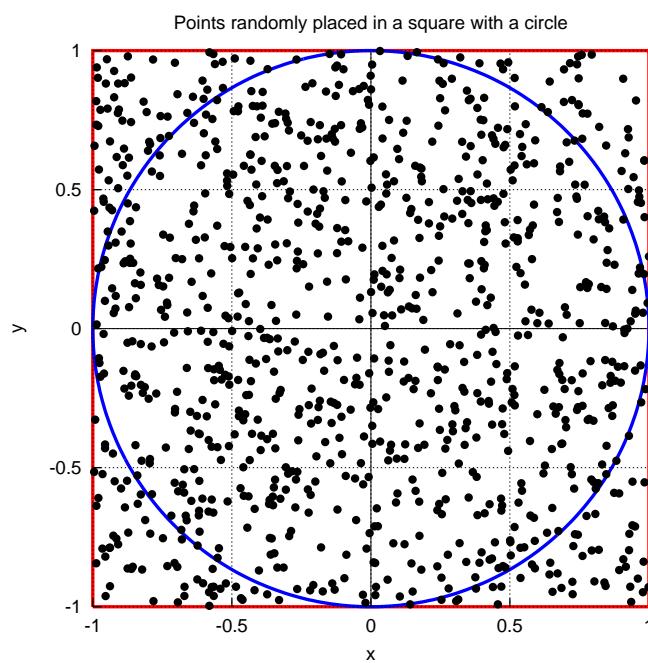


Figure 6.5: Using the *Monte Carlo method* to calculate the value of π .

CHAPTER 7

Modular Programming with Functions

A program is generally formed by a set of functions, which subsequently consist of many programming statements. Using functions, a large computing task can be broken into smaller ones; a user can develop application programs based upon what others have done instead of starting from scratch. For example, we have used standard functions `printf()` for output and `randint()` for generating random numbers. This chapter describes how functions are handled in C and how to write your own functions for your application programs. For user's convenience, one may collect all relevant functions as a library. A *library* consists of a set of functions. For example, Ch provides a standard mathematical library. Similarly, a simple plotting library is introduced for graphical visualization, which is important for many applications.

7.1 Function Definitions

Prerequisite: Understanding variable types, program structure, arithmetic and relational operators, looping

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.3, D5.5

Objective: Understand the concept of using functions to modularize a program.

A general format for declaring a function and an example is shown in Figure 7.1. The `return_type` is the function return type. It can be any valid type specifier. The `functionName` is the function name. The `argument_declaration` is a list of function arguments. Each argument in the argument declaration is separated by a comma. Functions should be defined at the beginning of a program.

7.1. Function Definitions

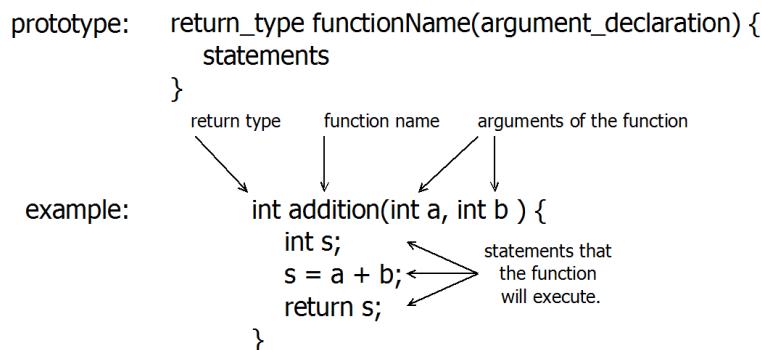


Figure 7.1: A general format for declaring a function and an example.

```

/* File: addition.ch
   Use function addition() to add two integers */

/* function definition for addition() */
int addition(int a, int b) {
    int s;      /* declare local variable inside function */

    s = a + b; /* addition of a and b */
    return s;   /* return the sum of a and b */
}

int sum;      /* declare local variable sum */

/* call function addition() to add 3 and 4, the return
   value from function is assigned to the variable sum */
sum = addition(3, 4);
printf("sum = %d\n", sum);

```

Program 7.1: Using the function addition().

7.1. Function Definitions

As shown in Figure 7.1 and Program 7.1, the function `addition()` has two arguments of `int` type. It calculates and returns the sum of the values of two passed arguments. The return type of the function is `int`. Function `addition()` is called by the program. The number of arguments in a function call shall match the number of arguments in the function definition. The function `addition()` has two arguments `a` and `b`. These arguments inside the function definition are called *formal arguments*. When the function `addition()` is called by the statement

```
sum = addition(3, 4);
```

the memory is allocated for variables `a` and `b` in the arguments of the function `addition()`. The values of 3 and 4 are then assigned to variables `a` and `b`, respectively. The passed arguments, such as 3 and 4, are called *actual arguments*.

A `return` statement terminates execution of the current function and returns control to its caller. A function may have any number of `return` statements. If a `return` statement with an expression such as

```
return expression;
```

is executed, the value of the expression is returned to the caller as the value of the function call expression. In this example, the statement

```
return s;
```

returns the value 7 from the variable `s`. This value is then assigned to the variable `sum` in the program. When the control of the program flow leaves the called function, the memory allocated for the variables `a` and `b` of the function argument and local variable `s` in the called function is freed. The output from Program 7.1 is as follows:

```
sum = 7
```

Alternatively, the function `addition()` can be defined by a simplified form as shown below.

```
int addition(int a, int b)
{
    return a+b;
}
```

Application: Calculating the Position of a Robot

Problem Statement:

The position coordinate p of a robot expressed as a function of time t in seconds is as follows:

$$p(t) = 2(t - 5)^2 + 5$$

Write a program to calculate the position when $t = 2$ seconds. Use a function to calculate the position with an independent variable for time.

7.2. Debugging Programs with Functions in ChIDE

```

/* File: posfunc.ch
   Calculate the position
   The position is calculated using a function */

/* definition of the function for position
   The data type of the argument and return value
   of the function is double */
double position(double t) {
    double p;          /* declare local variable */

    p = 2*(t-5)*(t-5)+5;
    return p;          /* return position p */
}

double p, t; /* declare local variables */

/* initialize t */
t = 2.0;

/* calculate the position by calling a function */
p = position(t);
printf("Position p = %lf meters\n", p);

```

Program 7.2: Calculating the position of a robot using a function for position.

Program 7.2 solves this problem using the function `position()` defined as follows:

```

double position(double t) {
    double p;          /* declare local variable */

    p = 2*(t-5)*(t-5)+5;
    return p;          /* return position p */
}

```

Unlike the function `addition()` in Program 7.1 with two arguments, the function `position()` has only one argument `t` for time and returns the position in the argument `p`. Because time must be represented using a decimal, the argument for a given time and return value for the position uses `double` type. The output of Program 7.2 is as shown below:

Position p = 23.000000 meters

 Do Exercises 1(a), 2(a), and 3 on page 138.

7.2 Debugging Programs with Functions in ChIDE

Prerequisite: Understanding variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1

7.2. Debugging Programs with Functions in ChIDE

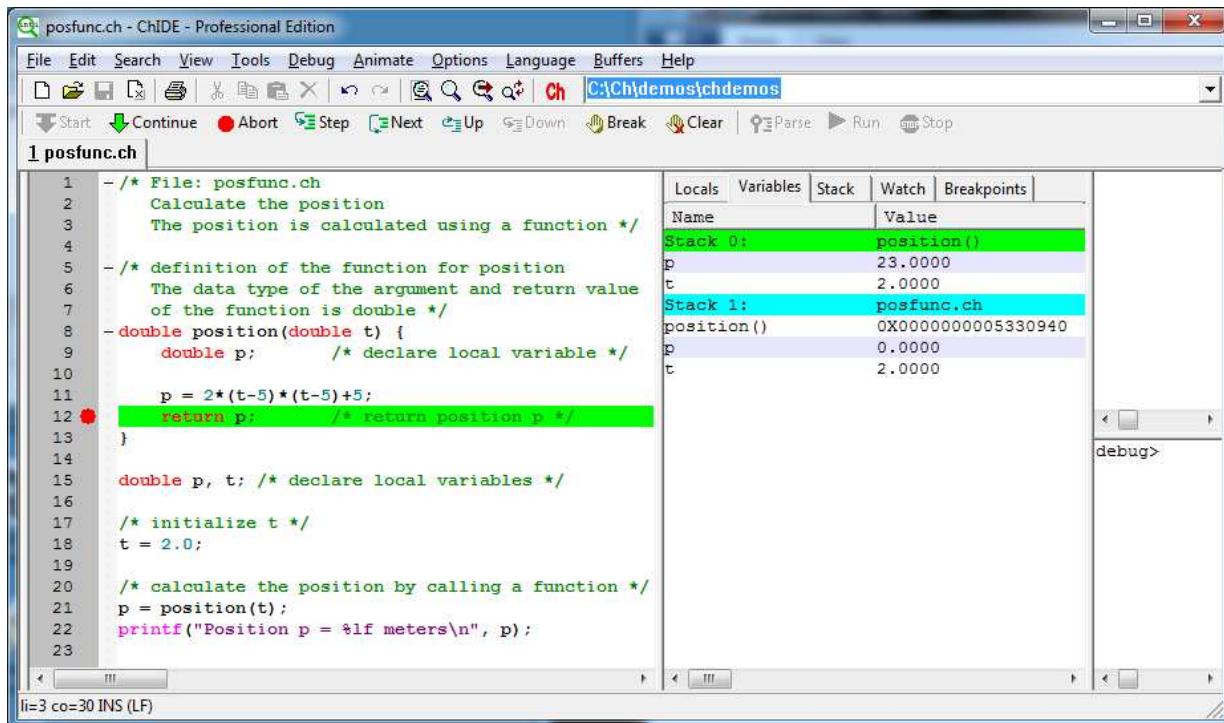


Figure 7.2: Debugging posfunc.ch in Program 7.2 showing values for all variables in different stacks in ChIDE.

Objectives: Use the ChIDE debugger to step through a function line by line or to step over a function. Identify local and global variables in a C program.

Using ChIDE to debug programs was introduced in section 2.4. In this section, how to debug programs with functions is described.

The command Step or Next will act the same until they reach a function call. Then, the command Step will step into a function whereas the command Next will step over the function to the next line. Figure 7.2 shows the execution of program posfunc.ch listed in Program 7.2 in ChIDE. The program stops in the function position() at line 12 with a breakpoint when it is called by the program posfunc.ch at line 21. The current executing line 12 is highlighted with the green color. Unlike previously displayed interfaces for ChIDE, ChIDE in Figure 7.2 is displayed in the vertical mode allowing the debug pane to show more information vertically. The command View->Vertical Split can be used to change the display in the vertical mode. In the vertical mode, the editing pane is on the left, debug pane in the middle, and input/output pane and debug command pane on the right, as shown in Figure 7.2.

Variable names and their corresponding values in all stacks can be displayed by clicking the menu Variables on the debug pane selection bar as shown in Figure 7.2. Stack levels are highlighted with the corresponding colors for the current line and executing lines in the calling functions in the editing pane. In this case, the program is stopped at line 12. Local variable names and their values of called function position() and as well as global variables of the program posfunc.ch are displayed in the debug

7.3. Functions for Mathematical Formulas

pane. The current running function has stack level 0, whereas level $n+1$ is the function that has called a function with stack level n . Function `position()`, the current running function, has stack level 0. The variables `p` and `t` inside this function have values 23.0 and 2.0. The values for variables `p` and `t` in the program `posfunc.ch` with stack level 0, are also displayed. Note that the function `position()` and the program `posfunc.ch` have their own variable named `p` with their own memory. Their values are different at this point. The variable `p` in the program `posfunc.ch` is 0, whereas the variable `p` in the function `position()` is 23.0. The function name `position` is a variable of function type. Its address is displayed in the debug pane as variables for program `posfunc.ch` at the stack level 1.

When you click the menu `Stack` on the debug pane selection bar, functions and program name with the corresponding stack level in each stack will be displayed in the debug pane.

The user can change the function stack during debugging. It can go `Up` to its calling function or program or move `Down` to the called function so the variables within its scope can be displayed or accessed in the debug pane. For example, when clicking command `Up` on the debug bar in Figure 7.2, the control flow of the program will move to the program `posfunc` at line 21. On the screen, line 12 will be highlighted with the green color whereas line 21 with the blue color, corresponding to the colors for different stacks shown in Figure 7.2. In Figure 7.2, the menu `Down` is not clickable. But, the menu `Down` will be clickable after the current stack is moved up to the program `posfunc.ch` after clicking the menu `Up`. Then, the debug pane will only show the program `posfunc.ch` at stack level 1 and their variables and corresponding values.

 Do Exercises 1(b) and 4 on page 138.

7.3 Functions for Mathematical Formulas

Prerequisite: Understanding variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1

Objective: Write computer code to include a user-defined function to convert Fahrenheit to Celsius.

Functions in C are well suited to handle numerical computation with equations and formulas. This can be illustrated by an example. Program 6.7 in Chapter 6 prints the relation of temperature in two different units of Fahrenheit and Celsius using the formula $y(x)$ in equation (7.1)

$$y(x) = \frac{5(x - 32)}{9} \quad (7.1)$$

inside a `for` loop in the range of $0 \leq x \leq 120$ with a step size of 10. Here the variable x is the temperature in Fahrenheit and y is the temperature in Celsius. For comparison, we will use a C function for the function $y(x)$ in equation (7.1) to obtain the same result. Equation (7.1) is translated into a C function. The function should have one argument. Because the variable x for this function uses real numbers, the argument and return type of the corresponding C function use `double`. Equation (7.1) is translated into the function `celsius()` shown in Program 7.3 with the following function prototype.

```
double celsius(double x)
```

7.4. Functions without Arguments or Return Values

```

/* File: celsiusfunc.ch
   Convert the temperature from Fahrenheit to Celsius
   using the function celsius()
   for x from 0 to 120 with step size 10 */

/* the function definition for the function celsius()  */
double celsius(double x) {
    double y;

    y = 5*(x - 32)/9;
    return y;
}

double x, x0, xf, xstep, y;
int i, n;

printf("Fahrenheit  Celsius\n");
printf("-----\n");
x0 = 0.0;                                // initial value for x
xf = 120.0;                               // final value for x
xstep = 10.0;                              // step size for x
for(x = x0; x <= xf; x = x+xstep) {
    y = celsius(x);
    printf("%5.1f %12.2lf\n", x, y); // display the result
}

```

Program 7.3: Using the function `celsius()` for the mathematical equation (7.1).

Inside the `for` loop in Program 7.3, function `celsius()` is called in each iteration. The output from Program 7.3 is the same as one shown in Figure 6.4.

 Do Exercises 1(c) and 2(b) on page 138.

7.4 Functions without Arguments or Return Values

Prerequisite: Understanding variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.3, D5.5

Objective: Understand the concept of a void type when a function either does not require a value sent to it or has a need to return a value after it is executed.

If a function does not return a value, the type specifier `void` can be used. For example, the function prototype below indicates that the function `func1()` has an argument of `int` type without returning a value.

```
void func1(int)
```

7.4. Functions without Arguments or Return Values

A function requiring no argument can be prototyped with the single type specifier **void**. For example,

```
int func(void)
```

A function without argument and return value can be prototyped as

```
void func3(void)
```

This is useful when the function's sole purpose is to display a printed message, as will be presented in Program 7.4.

Application: Testing the Result for Addition of Two Random Numbers with Random Messages

Problem Statement:

Write a program that generates two random integers ranging from 1 to 10. The random numbers generated by the program shall be different at each run. Then prompt the user to enter the sum of the two numbers. If the user enters the correct answer, it prints a correct comment. If it is wrong, it prints an incorrect comment and allows the user to enter another answer until it is right. Correct or incorrect comments are randomly printed. Use two functions, one for handling correct answers and the other for incorrect answers. Response to a correct answer may be "Correct!", "Good Job!", or "Great!". Response to an incorrect answer may be "Incorrect. Please try again.", "Wrong. Try again.", or "No. Enter another answer.".

7.4. Functions without Arguments or Return Values

```

/* File: addtestf.ch
   Test the result for addition of two numbers in the range [1, 10]
   with random messages */

/* function to print a random message for a correct answer */
void correctMessage(void) {
    int randnum = randint(1, 3);
    if(randnum==1) {
        printf("Correct!\n");
    }
    else if(randnum==2) {
        printf("Good Job!\n");
    }
    else {
        printf("Great!\n");
    }
}

/* function to print a random message for an incorrect answer */
void incorrectMessage(void) {
    int randnum = randint(1, 3);
    if(randnum==1) {
        printf("Incorrect. Please try again.\n");
    }
    else if(randnum==2) {
        printf("Wrong. Try again.\n");
    }
    else {
        printf("No. Enter another answer.\n");
    }
}

int x, y, answer; /* two random numbers and the user input answer */

x = randint(1, 10); /* get x in the range [1, 10] */
y = randint(1, 10); /* get y in the range [1, 10] */

printf("What is %d + %d? ", x, y);
scanf("%d", &answer); /* get the user's answer */

/* while the user's answer is incorrect, continue to get the answer */
while(answer != (x + y)) {
    incorrectMessage();
    printf("What is %d + %d? ", x, y);
    scanf("%d", &answer);
}
correctMessage();

```

Program 7.4: A program to test the result for addition of two random numbers with random messages.

Program 6.8 in Chapter 6 is modified to display random messages using two functions as shown in Program 7.4. The function `correctMessage()` displays one of three random messages for the correct answer. The function call `randint(1, 3)` 1, 2, or 3. The function `incorrectMessage()` displays one of three random messages for a correct answer. Both functions neither have arguments nor return values. These two functions are defined at the beginning of the program. A sample execu-

7.5. Plotting Functions for Graphical Display

tion of Program 7.4 is shown below:

```
What is 4 + 5? 3
No. Enter another answer.
What is 4 + 5? 8
Wrong. Try again.
What is 4 + 5? 9
Good Job!
```

 Do Exercises 5, 6, and 7 on page 139.

7.5 Plotting Functions for Graphical Display

Prerequisite: Understanding variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.3, D5.5

Objective: Utilize the member function **plot.func2D()** of the **CPlot** graphical library to plot functions.

7.5.1 Plotting a Curve Using the Member Function **func2D()**

In section 4.2 in Chapter 4, we learned how to plot a straight line using two points by the member function **plot.line()**. We cannot zoom in on a point in such a generated line on a screen to obtain accurate values of the x and y coordinates of the point. In this section, we will use the member function **plot.func2D()** to plot a function. Depending on the number of points used to plot the function, we can zoom in on a point of the line or curve generated by this member function to obtain accurate values of the x and y coordinates of the point

The member function

```
plot.func2D(x0, xf, num, func);
```

will plot a function defined as `func()` in the range `[x0, xf]` with the number of points specified by the third argument `num`. Adjacent points are connected by lines. The function `func()` shall have the following function prototype with an argument of **double** type and return type of **double**.

```
double func(double x);
```

For example, Program 7.5 plots the mathematical function $y(x)$ of equation (7.1) in section 7.3. The generated plot for function $y(x)$ is shown in Figure 4.3 in Chapter 4. In Program 7.5, the statement

```
plot.func2D(x0, xf, num, celsius);
```

plots the function `celsius()` defined for the linear relation $y = 5(x - 32)/9$ with 500 points for x in the range of -10 to 110 . If the above statement is replaced by the statement

7.5. Plotting Functions for Graphical Display

```

/* File: celsiusplot.ch
   Plot the temperature relationship between Fahrenheit and to Celsius
   using the function celsius(x) for x from -10 to 110 with 500 points */
#include <chplot.h> /* for using CPlot */

/* definition of the function celsius() to be plotted */
double celsius(double x) {
    double y;
    y = 5*(x - 32)/9;
    return y;
}

CPlot plot;
double x0 = -10.0, xf = 110.0; /* initial and final values for x */
int num = 500; /* number of data points for (x, y) for plotting */

plot.title("Temperature Relation");
plot.label(PLOT_AXIS_X, "Fahrenheit");
plot.label(PLOT_AXIS_Y, "Celsius");
/* plot celsius() from x0 to xf with num points */
plot.func2D(x0, xf, num, celsius);
plot.plotting();

```

Program 7.5: A program to plot function `celsius()` using the member plotting function `func2D()`.

```
plot.func2D(x0, xf, 2, celsius);
```

the generated plot is equivalent to the one generated with the member function `plot.line()` with two points.

 Do Exercises 1(d) and 2(c) on page 138.

7.5.2 Zooming in to Find the Coordinates of a Point on a Plot

You can zoom in and zoom out on a plot. For the plot, generated by Program 7.5 and shown in Figures 4.3 and 7.3, you can obtain a more accurate value for an x-intercept or y-intercept if you zoom in on the area of intersection. To zoom in, move the mouse while holding down the right mouse button. The x and y coordinates of the upper left and lower right corners of the zoomed area will be displayed on the screen, as shown in Figure 7.3. While the mouse is focused on the plot, typing ‘p’ zooms out, typing ‘n’ zooms in, and typing ‘a’ or ‘u’ will take the plot to the original state. You may also click the 4th menu on the plot, as shown in Figure 7.3, to apply the previous zoom settings, the 5th menu to apply the next zoom settings.

When you write a program with a plot to be viewed with zooming, you should follow the design guidelines below.

1. The more data points for a plot, the finer resolution you can zoom in. You may use 500 or more data points for each curve on a plot for zooming operations.
2.  If a program calls the plotting member function `plot.ticsRange()`, tick marks on the plot will not be automatically changed when you zoom in on an area of the interest on the plot. Therefore, to use the zooming capabilities, you should not use `plot.ticsRange()`.

 Do Exercises 1(e) and 8 on page 138.

7.5. Plotting Functions for Graphical Display

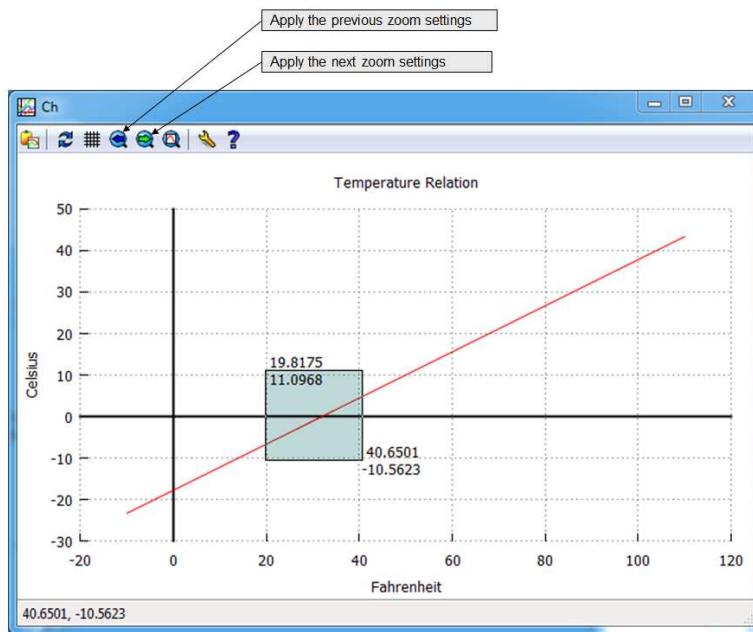


Figure 7.3: Zooming in on the x-intercept and applying the previous and next zoom settings.

Application: Plotting the Position for a Robot

As an example, we can plot the position of a robot.

Problem Statement:

The position coordinate of a robot expressed as a function of time t in seconds is as follows:

$$p(t) = 2(t - 5)^2 + 5$$

Write a program to plot the position p for $t = 0$ to $t = 10$ seconds with 6 points. Modify the program to plot the position with 21 points.

Program 7.6 uses the member function **func2D()** to plot the position of the robot with 6 data points shown in Figure 7.4. Because we only used 6 points, the position curve is not smooth. If we change the program with 21 points for the variable `num` in Program 7.6, the position curve will be smooth as shown in Figure 7.5.

7.5. Plotting Functions for Graphical Display

```

/* File: posplot.ch
   Plot the positions versus time for t from 0 to 10 seconds.
   It uses 6 points of data for the plotting */
#include <chplot.h>

/* the function position() to be plotted */
double position(double t) {
    double p;

    p = 2*(t-5)*(t-5)+5;
    return p;
}

CPlot plot;
double t0 = 0, tf = 10.0; /* time t from t0 to tf */
int num = 6;             /* the number of points is 6 */

/* plot the function position() from t0 to tf with 6 points.
   The curve in the plot is not smooth for 6 points.
   The value for num can be changed to 21 to get a smooth curve.
   The title of the plot is "Position Plot".
   the label for x-coordinate is "time (seconds)",
   the label for y-coordinate is "position (meters)" */
plot.title("Position Plot");
plot.label(PLOT_AXIS_X, "time (s)");
plot.label(PLOT_AXIS_Y, "position (m)");
plot.func2D(t0, tf, num, position);
plot.plotting();

```

Program 7.6: Plotting the positions of a robot using 6 points.

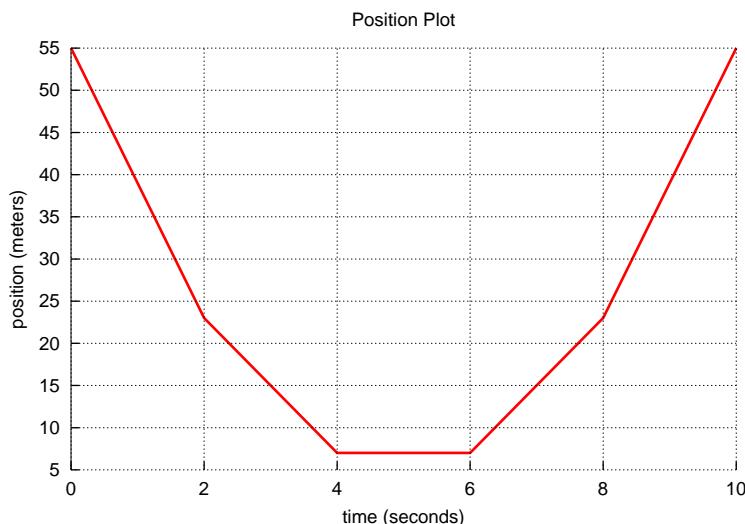


Figure 7.4: The position plot for the position $p = 2(t - 5)^2 + 5$ from Program 7.6, Program 8.6 in Chapter 8, and Programs 9.3 and 9.4 in Chapter 9.

7.5. Plotting Functions for Graphical Display

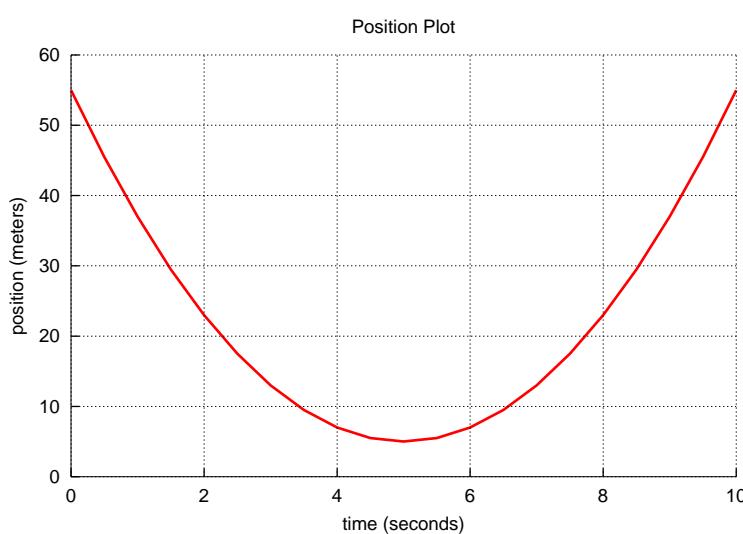


Figure 7.5: The position plot for the position $p = 2(t - 5)^2 + 5$ from Program 7.6 with num = 21 and Program 8.6 in Chapter 8 for N with 21 data points.

Do Exercise 9 on page 139.

7.5.3 Plotting Multiple Curves Using Different Functions in a Single Plot

It would be nice to merge two curves in Figures 7.4 and 7.5 in a single plot for comparison. The plotting class **CPlot**. can be conveniently used to draw multiple curves in a single plot.

Program 7.7 plots two position curves in a single plot shown in Figure 7.6. In Program 7.7, member function **plot.func2D()** is called twice to add two sets of plotting data for the object **plot**. The first curve has 6 points and the second one has 21 points. To distinguish these two curves, the member function **plot.legend()** is called in the form of

```
plot.legend("legend", datanum);
```

to add legends to the plot. The first argument is a string for the legend. The second argument is the curve number or data set number to associate with the legend.

The Ch plot uses enhanced text for strings. such as title, labels, and legends. The title of the curve " $p(t) = 2(t - 5)^2 + 5$ " with an exponent, instead of, $p(t) = 2(t - 5)^2 + 5$ will be displayed. Special symbols for the enhanced text can be found in the section **enhanceText()** for the header file **chplot.h** in **Ch Reference Guide**.

Do Exercise 10 on page 139.

7.5.4 Plot Types and Filling an Area with Color

By default, two adjacent points for plotting are connected by a line as if the plot type was specified by the statement

```
plot.plotType(PLOT_PLOTTYPE_LINE, datanum);
```

7.5. Plotting Functions for Graphical Display

```

/* File: posfunc2D.ch
   Plot two position curves on the same figure with 6 and 21 points each. */
#include <chplot.h> /* for class CPlot for plotting */

/* function position() to be plotted */
double position(double t) {
    double p;

    p = 2*(t-5)*(t-5)+5;
    return p;
}

double t0 = 0, tf = 10.0;           // time t from t0 to tf
int num1 = 6, num2 = 21;           // with 6 and 21 points
int datanum=0;                   // number of plotting data set
CPlot plot;                      // declare plot

plot.title("Position p(t)= 2(t-5)^2+5"); // set title p(t)=2(t-5)^2+5
plot.label(PLOT_AXIS_X, "time (seconds)"); // set the label on the x-axis
plot.label(PLOT_AXIS_Y, "position (meters)"); // set the label on the y-axis
plot.func2D(t0, tf, num1, position); // set the 1st function position()
                                      // to be plotted from t0 to tf with num1 points
plot.legend("6 points", datanum); // set the legend for the 1st curve
plot.func2D(t0, tf, num2, position); // set the 2nd function position()
                                      // to be plotted from t0 to tf with num2 points
datanum++;
plot.legend("21 points", datanum); // set the legend for the 2nd curve
plot.plotting();                // plot and display it!

```

Program 7.7: Plotting two position curves in a single plot.

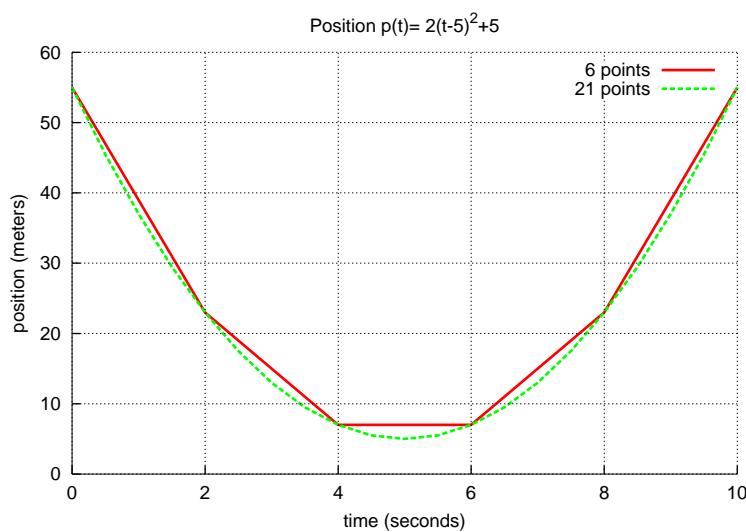


Figure 7.6: The plot generated by Program 7.7, Program 8.9 in Chapter 8, and Program 9.5 in Chapter 9.

7.5. Plotting Functions for Graphical Display

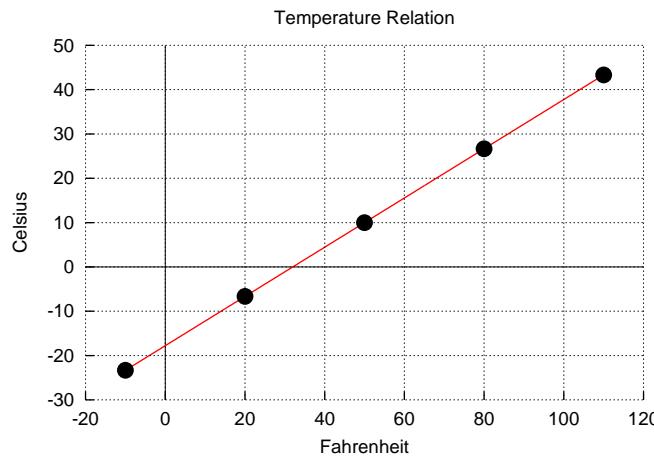


Figure 7.7: A plot with points generated by Program 7.8.

The default attributes of a line can be modified by the member function `plot.lineType()` as described in section 4.8.1 in Chapter 4. Furthermore, the default line plotting can be changed by calling the member function `plot.plotType()` with different arguments.

Point Type

In some applications, it may be desirable to display each point without connecting them together as a scatter plot. The function call

```
plot.plotType(PLOT_PLOTTYPE_POINTS, datanum);
```

will display data in a scatter plot. The default attributes of points can be modified by the member function `plot.pointType()` as described in section 4.8.2 in Chapter 4.

For example, in Program 7.8, the following statements

```
plot.func2D(x0, xf, num2, celsius);
datanum = datanum + 1;
plot.plotType(PLOT_PLOTTYPE_POINTS, datanum);
plot.pointType(datanum, pointType, pointSize, "black");
```

are added to Program 7.5 to generate 5 points based on the same function `celsius()`. The plot generated by Program 7.8 is shown in Figure 7.7.

Do Exercise 11 on page 140.

Filling an Area with Color

Program 7.9 uses the following statement

```
plot.plotType(PLOT_PLOTTYPE_FILLEDCURVES, datanum, "y1=-1", "yellow");
```

to fill the area between the curve $y = x^2 - 5x + 6$ and the horizontal line $y = -1$ with the yellow color, as shown in Figure 7.8. The member function `plot.plotType()` in this case has four arguments. The first argument `PLOT_PLOTTYPE_FILLEDCURVES` is a macro defined in the header file `chplot.h` for a plot type to fill an area. The second argument `datanum` specifies the number for the data set to which the filled curve applies. The third argument specifies an axis for filling the area. In this example, the member function fills the area between the curve created by the data points in the data set `datanum` and the horizontal line $y = -1$ specified by the string "`y1=-1`". The third argument correctly places the shading. The fourth argument "`yellow`" specifies the color for the filled area.

The statement

7.5. Plotting Functions for Graphical Display

```

/* File: plottype.ch
Plot the temperature relationship between Fahrenheit and Celsius
using the function celsius(x) for x from -10 to 110 with 500 points
for a line, with 5 points for a scatter plot. */
#include <chplot.h> /* for using CPlot */

/* definition of the function celsius() to be plotted */
double celsius(double x) {
    double y;
    y = 5*(x - 32)/9;
    return y;
}

CPlot plot;
double x0 = -10.0, xf = 110.0; /* initial and final values for x */
int num1 = 500; /* number of data points for plotting a line */
int num2 = 5; /* number of data points for plotting scatter points */
int datanum=0;
int pointType=7, pointSize = 2;

plot.title("Temperature Relation");
plot.label(PLOT_AXIS_X, "Fahrenheit");
plot.label(PLOT_AXIS_Y, "Celsius");
/* plot celsius() from x0 to xf with num1 points
   connecting adjacent two points with lines */
plot.func2D(x0, xf, num1, celsius);

/* plot celsius() from x0 to xf with num2 points for scatter points */
plot.func2D(x0, xf, num2, celsius);
datanum = datanum + 1;
plot.plotType(PLOT_PLOTTYPE_POINTS, datanum);
plot.pointType(datanum, pointType, pointSize, "black");

plot.plotting();

```

Program 7.8: Using the point type **PLOT_PLOTTYPE_POINTS**.

7.6. Passing Arguments of Function by References

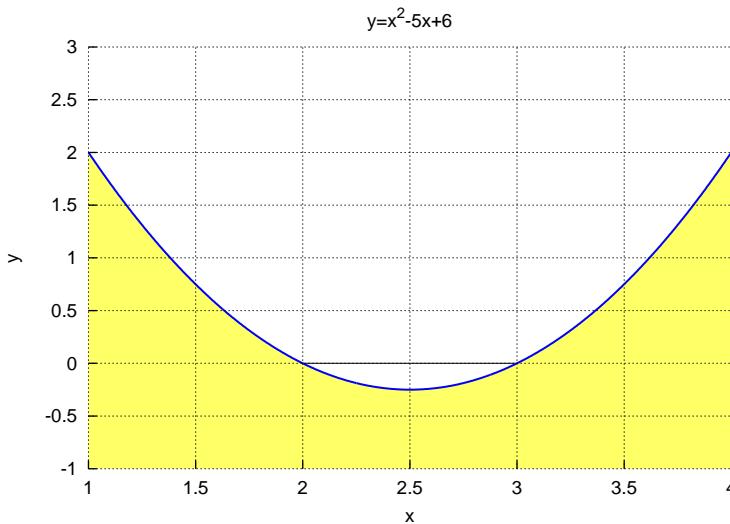


Figure 7.8: The graph for the polynomial curve $y = x^2 - 5x + 6$ with 3 pixels in width and blue color, and filling the area between the curve and horizontal line $y = -1$ with yellow color, generated by Program 7.9.

```
plot.axisRange(PLOT_AXIS_Y, -1, 3);
```

sets the highest and lowest y values. If you want to shade down, you use the low value. If you want to shade up, you use the high value.

The function call

```
plot.lineType(datanum, lineType, lineWidth, "blue");
```

specifies the line type, width, and color. The line type value of 1 is for a solid line. The line type value of 0 is for a dotted line. In some applications such as shading an area under an inequality in algebra, you may want to draw a dotted line for the curve. If you change the value for the variable `lineType` to 0 in Program 7.9, the generated plot will have a dotted curve as shown in Figure 7.9. The program `plottype3.ch` distributed along with `plottype2.ch` will also generate Figure 7.9.



Note that if the x-axis range set by the member function `plot.axisRange()` is different from the actual data point, the graph with the filled curve may not appear correctly. To avoid any possible mis-interpretation of a plot, do not call `plot.axisRange()` to set the x-axis.



To make a line or curve on the filled area visible, you need to draw the filled area first, then draw the line or curve, as shown in Program 7.9.

Do Exercises 12 and 13 on page 140.

7.6 Passing Arguments of Function by References

A function can only return one argument. If we want to obtain more than one result from a function, we need to pass the results back through its arguments.

Normally, when a function is called, the values of the actual parameters are copied into formal parameters local to the called function. When a formal parameter is used as an *lvalue* (the object that can occur at

7.6. Passing Arguments of Function by References

```

/* File: plottype2.ch
   Fill the area between the parabola
   (y = x*x-5x+6 for x from 1 to 4 with 500 points)
   and horizontal line y=-1 with yellow color.
   The range of y-axis is from -1 to 3.
   Draw the parabola with the width of 3 pixels in blue */
#include <chplot.h> /* for CPlot */

double func(double x) {
    double y;
    y = x*x - 5*x + 6;
    return y;
}

int datanum=0;           // number of plotting data set
int lineType=1, lineWidth=3; // solid line width 3 pixels
CPlot plot;

plot.title("y=x^2-5x+6");
plot.label(PLOT_AXIS_X, "x");
plot.label(PLOT_AXIS_Y, "y");
plot.axisRange(PLOT_AXIS_Y, -1, 3);

/* First, fill the area between the parabola and
   horizontal line y=-1 with yellow color */
plot.func2D(1, 4, 500, func);
plot.plotType(PLOT_PLOTTYPE_FILLEDCURVES, datanum, "yl=-1", "yellow");

/* Then, draw the parabola with the width of 3 pixels in blue */
plot.func2D(1, 4, 500, func);
datanum = datanum + 1;
plot.lineType(datanum, lineType, lineWidth, "blue");

plot.plotting();

```

Program 7.9: Plotting the polynomial curve $y = x^2 - 5x + 6$ with 3 pixels in width and blue color, and filling the area between the curve and and horizontal line $y = -1$ with yellow color.

7.6. Passing Arguments of Function by References

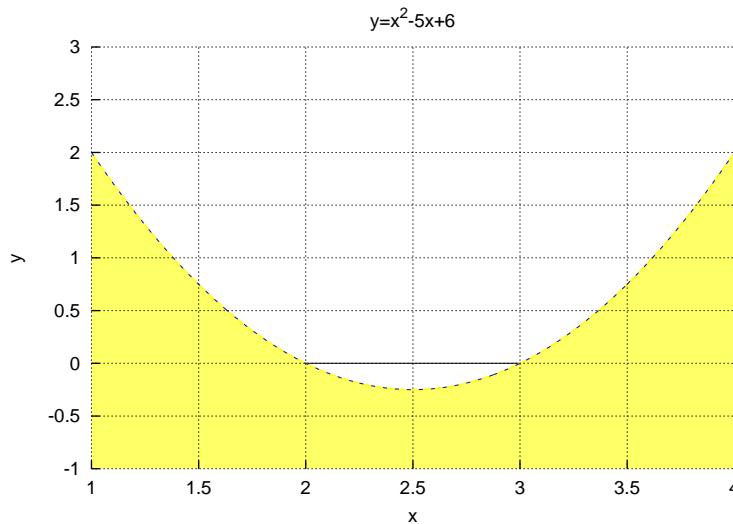


Figure 7.9: The graph for the polynomial curve $y = x^2 - 5x + 6$ with 3 pixels in width and blue color using a dotted line, and filling the area between the curve and and horizontal line $y = -1$ with yellow color.

the left side of an assignment statement), only the local copy of the parameter will be altered. This method of passing the arguments of a function is called ***pass by value***.

If the user wants the called function to alter its actual parameters in the program, the address of an argument should be copied into the formal parameter of a function. Inside the function, the address is used to access the actual argument used in the program. This means that when the formal parameter is used as an lvalue, the parameter will affect the variable used to call the function. The reference type of a function argument can be declared with an ampersand ($\&$) in front of the variable name. This method of passing the arguments of a function is called ***pass by reference***. The pass by reference is often used in a robot control program to obtain information, such as the position of the robot, through a function.

Application: Calculating the Area and Circumference of a Metal Disc

For a metal disc with a radius r , the area and circumference of the disc can be calculated by the following formulas.

$$\text{area} = \pi r^2 \quad (7.2)$$

$$\text{circum} = 2\pi r \quad (7.3)$$

We can use a function to calculate the area and circumference of a metal disc with a given radius. Because a function can only return one argument, we could not return both area and circumference from the function. But, we can write a function to calculate the area and circumference of a disc and pass these results back to the program by reference, as shown in Program 7.10.

7.6. Passing Arguments of Function by References

```

/* File: disref.ch
   Use a function to calculate the area and circumference of a disc.
   Pass the results back by reference. */

/* the function disref() calculates area and circumference
   of a disc with a given radius. */
void disref(double radius, double &area, double &circum) {
    area = M_PI * radius * radius;
    circum = 2*M_PI*radius;
}

double radius;          /* radius of the disc */
double area, circum;   /* area and circumference of the disc */

radius = 3.5;           /* radius is 3.5 meters */
disref(radius, area, circum);
printf("area = %.2lf square meters\n", area);
printf("circumference = %.2lf meters\n", circum);

```

Program 7.10: Passing both area and circumference of a metal disc to the program through reference.

In Program 7.10, the function `disc()` with the prototype

```
void disc(double radius, double &area, double &circum)
```

takes the radius of a disc as the input. The calculated area and circumference are the output of the function. The arguments `area` and `circum` for the output are declared with an ampersand (&) in front of the variable names. They are passed by reference through variables `area` and `circum` to the program by the function call

```
disc(radius, area, circum);
```

With a given radius of 3.5 meters, the output from Program 7.10 is as follows:

```
area = 38.48 square meters
circumference = 21.99 meters
```

 Do Exercise 14, on page 141.

7.6.1 ‡ Solving Quadratic Equations

A quadratic equation is in the form of

$$ax^2 + bx + c = 0 \quad (7.4)$$

where a , b , and c are real-number constants and $a \neq 0$. The solutions of the quadratic equation (7.4) can be obtained by the formulas

$$x_1 = \frac{-b + \sqrt{b^2 - 4ac}}{2a}, \quad (7.5)$$

$$x_2 = \frac{-b - \sqrt{b^2 - 4ac}}{2a}. \quad (7.6)$$

The solutions of a quadratic equation depend on the value of the **discriminant** ($b^2 - 4ac$). If $b^2 - 4ac < 0$, then the equation has no solution. If $b^2 - 4ac = 0$, then the equation has one solution called the **double root**. If $b^2 - 4ac > 0$, the equation has two distinct solutions. The function `quadratic()` in Ch for solving a quadratic equation is implemented as shown in Program 7.11 with the following function prototype.

7.7. Mathematical Functions in the Standard C Library

```
/* File: quadratic.chf
   Solve for two solutions x1 and x2 of a quadratic equation ax^2+bx+c=0 */
int quadratic(double a, double b, double c, double &x1, double &x2) {
    x1 = (-b+sqrt(b*b-4*a*c))/(2*a);
    x2 = (-b-sqrt(b*b-4*a*c))/(2*a);
    if(b*b-4*a*c > 0) {
        return 2; // two solutions
    }
    else if(b*b-4*a*c == 0) {
        return 1; // one solution
    }
    else {
        return -1; // no solution
    }
}
```

Program 7.11: The function **quadratic()**.

```
/* File: quadratic.ch
   Solve the quadratic equation x*x -5x +6 = 0  */
double a=1, b=-5, c = 6;
double x1, x2;

quadratic(a, b, c, x1, x2);
printf("Solutions for x*x-5x+6=0 are x1=% .2lf and x2=% .2lf\n", x1, x2);
```

Program 7.12: Solving the quadratic equation $x^2 - 5x + 6 = 0$ using the function **quadratic()**.

```
int quadratic(double a, double b, double c, double &x1, double &x2)
```

where arguments *a*, *b*, and *c* are the coefficients of the quadratic equation, and arguments *x1* and *x2* are solutions. The function returns the number of solutions.

Program 7.12 shows how the Ch built-in function **quadratic()** is used to solve the quadratic equation

$$x^2 - 5x + 6 = 0 \quad (7.7)$$

with *a* = 1, *b* = -5, and *c* = 6. The output from Program 7.12 is as follows:

```
Solutions for x*x-5x+6=0 are x1=3.00 and x2=2.00
```

 Do Exercises 15 and 16 on page 141.

7.7 Mathematical Functions in the Standard C Library

Prerequisite: Understanding variable types, program structure, arithmetic and relational operators

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

7.7. Mathematical Functions in the Standard C Library

```

/* File: sines.ch
   Plot sin(x) and sin(2x) from 0 to 2 PI */
#include <chplot.h> // for CPlot

/* the function sine() */
double sine(double x) {
    double y;
    y = sin(x);
    return y;
}

double sine2(double x) {
    double y;
    y = sin(2*x);
    return y;
}

double x0 = 0, xf = 2*M_PI;           // for x from x0 to xf
int num = 500;                      // number of points
int datanum=0;                      // number of plotting data set
CPlot plot;                          // declare plot

plot.title("Sine functions sin(x) and sin(2x)");
plot.label(PLOT_AXIS_X, "x");        // set the label on the x-axis
plot.label(PLOT_AXIS_Y, "y");        // set the label on the y-axis
plot.func2D(x0, xf, num, sine);     // set the 1st function sine()
                                    // to be plotted from x0 to xf with num points
plot.legend("sin(x)", datanum);     // set the legend for the 1st curve
plot.func2D(x0, xf, num, sine2);    // set the 2nd function sine2()
datanum = datanum +1;
plot.legend("sin(2x)", datanum);    // set the legend for the 2nd curve
plot.plotting();                   // plot and display it!

```

Program 7.13: Plotting the trigonometric functions $\sin(x)$ and $\sin(2x)$.

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3

Objective: Recognize that there are several mathematical functions built into the standard C library.

Most elementary mathematical functions, including trigonometric functions, are readily available in C. The commonly used trigonometric functions **sin()**, **cos()**, **tan()** for sine, cosine and tangent, respectively, return a value of **double** type. The units for the angular argument of these trigonometric functions are in radians, not in degrees. A list of mathematical functions is as follows: **abs()**, **acos()**, **acosh()**, **asin()**, **asinh()**, **atan()**, **atan2()**, **atanh()**, **ceil()**, **conj()**, **cos()**, **cosh()**, **exp()**, **fabs()**, **floor()**, **fmod()**, **frexp()**, **hypot()**, **log()**, **log10()**, **max()**, **min()**, **modf()**, **pow()**, **real()**, **sin()**, **sinh()**, **sqrt()**, **tan()**, **tanh()**. These mathematical functions are very useful for engineering and science applications.

For example, Program 7.13 uses the math function **sin()** and plotting member function **plot.func2D()** to plot the periodic trigonometric functions $\sin(x)$ and $\sin(2x)$ for x in the range of 0 to 2π as shown in Figure 7.10.

 Do Exercises 17 and 18 on page 142.

7.8. Chapter Summary

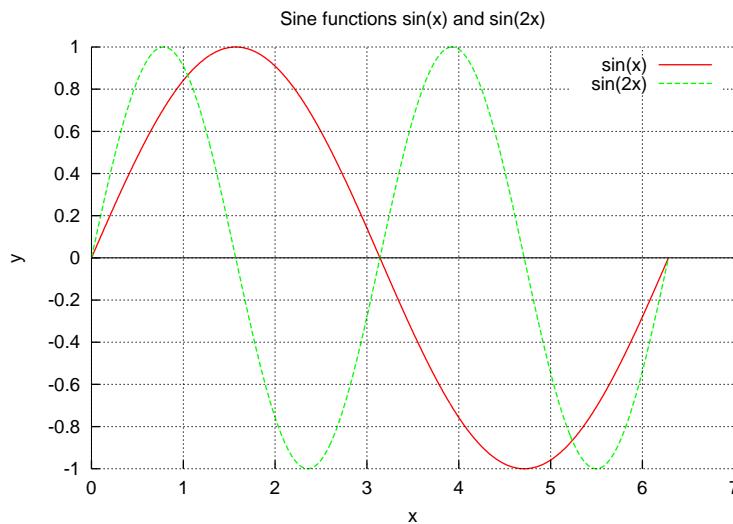


Figure 7.10: The trigonometric functions $\sin(x)$ and $\sin(2x)$.

7.8 Chapter Summary

7.8.1 Programming Tips

Good Programming Practice

1. To make the code more readable, name functions using lowercase letters. For a variable name with multiple words, separate words with underscore or use a capital letter for words other than the first. For example,

```
double pos_train(double t);
double posTrain(double t);
```

2. Insert a space after the comma. For example,

```
int x, y;
func(x, y);
```

3. Do not use the member function **plot.ticsRange()** for plotting if you would like to zoom in on the plot.
4. For plotting a filled curve, do not use the member function **plot.axisRange()** to set the x-axis range.
5. For plotting a filled curve, draw the filled area first, then draw a line or curve to make the line or curve on the filled area visible,

Common Programming Errors

1. Forget to return a value for a function that should return a value.
2. Forget to place a function prototype at the beginning, if the return type of the function is not int and the function is called before its definition. For example,

7.9. Exercises

```

/* The function prototype below is missing
   double func2();
*/
int func() {
    double d;
    d = func2();
    return 0;
}
double func2() {
    /* code */
}

```

3. The number of arguments for a function does not match. For example,

```

int func(double x, int n);           // need two arguments
i = func(x);                      // only one argument

```

7.8.2 Terminology

General Concepts

actual argument	call function	
formal argument	function	
function prototype	library	function name

Ch Reserved Words

quadratic()	return	sin()
vertex()	void	

ChIDE Related Concepts

Debug Commands->Down	Debug Commands->Next	Debug Commands->Step
Debug Commands->Up	Debug Pane->Stack	Debug Pane->Variables

The Plotting Class **CPlot**

CPlot.func2()	CPlot.enhanceText()	CPlot.plotType()
PLOT_PLOTTYPE_FILLEDCURVE	PLOT_PLOTTYPE_LINE	PLOT_PLOTTYPE_POINTS

7.9 Exercises

- For the function $f_1(x) = 2x - 4$, (a) write a program `fun1.ch` to calculate the value of the function using a C function at $x = 3.5$. (b) Run the program `fun1.ch` in ChIDE using the command Next. Then, run the program using the command Step. (c) Write a program `fun11.ch` to calculate the function values using a C function for x in the range of $-1 \leq x \leq 5$ with a step size of 0.25, and display the output in the format shown in Figure 6.4. (d) Write a program `fun1plot.ch` to plot the function using the plotting member function `func2D()` with 500 points. (e) Run the program `fun1plot.ch`. Zoom in on the plot to find the x-intercept and y-intercept.
- For the function $f_2(x) = -x^2 + 5x - 6$, (a) write a program `fun2.ch` to calculate the value of the function using a C function at $x = 3.5$. (b) Write a program `fun22.ch` to calculate the function values using a C

7.9. Exercises

function for x in the range of $-1 \leq x \leq 5$ with a step size of 0.25, and display the output in the format shown in Figure 6.4. (c) Write a program `fun2plot.ch` to plot the function using the plotting member function `func2D()` with 500 points.

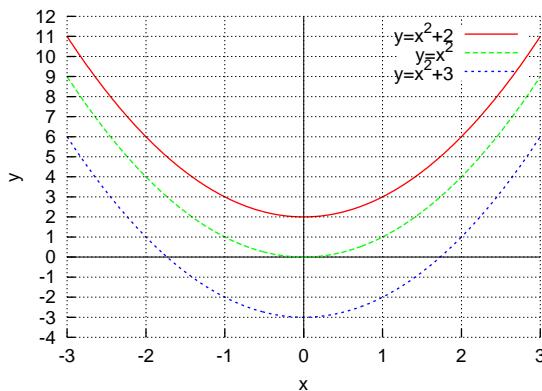
3. The formula for the volume of a sphere is $\frac{4}{3}\pi r^3$, where r is the radius of the sphere. Write a program `sphere.ch` using a function to return the volume of a sphere with the argument for the radius of the sphere. Test your program with a radius of 5 meters.
4. Write a program `areaperimeter.ch` that calculates the area and perimeter of a rectangle. The area and perimeter are calculated using two separate functions, which both take two arguments of `double` type for width and length of the rectangle. Calculate the area and perimeter using these two functions in the main program for a rectangle with width and length of 2 cm and 5.5 cm, respectively. Run the program `fun1.ch` in ChIDE using the command `Next`. Then, run the program using the command `Step`.
5. (a) Write a program `frandommula.ch` that generates two random integers ranging from 1 to 10. The random numbers generated by the program shall be different at each run. Then prompt the user to enter the product of the two numbers. If the user enters the correct answer, it prints a correct comment. If it is wrong, print an incorrect comment and allow the user to enter another answer until it is right. Correct or incorrect comments are randomly printed. Use two functions, one for handling correct answers and the other for incorrect answers. Response to a correct answer may be "Correct!", "Good Job!", or "Great!". Response to an incorrect answer may be "Incorrect. Please try again.", "Wrong. Try again.", or "No. Enter another answer.".
 (b) Modify the program as `frandommulb.ch` to ask the user a total of ten addition problems. At the end of the 10th question, print a message to tell the user how many problems were answered correctly. If the user has more than 8 correct solutions, give a complementary comment. For less than 6 correct solutions, give an encouragement statement. Note that the user should only have one chance to answer each question.
6. In Exercise 5, two random numbers in the range from 1 to 10 are multiplied. Write programs `frandomsuba.ch` and `frandomsubb.ch` to do the same for subtraction of two random numbers in the range from 1 to 100.
7. (a) Write a program `frandomaddsub.ch` to generate two random integers ranging from 1 to 10. The random numbers generated by the program shall be different at each run. A random operation of either addition or subtraction for these two numbers will be selected. Then prompt the user to enter the result of the operation. If the user enters the correct answer, it prints a correct comment. If it is wrong, print an incorrect comment and allow the user to enter another answer until it is right. Correct or incorrect comments are randomly printed. Use two functions, one for handling correct answers and the other for incorrect answers. Response to a correct answer may be "Correct!", "Good Job!", or "Great!". Response to an incorrect answer may be "Incorrect.", "Wrong.", or "Bad answer.". Ask the user a total of ten problems. At the end of the 10th question, print a message to tell the user how many problems were answered correctly. If the user has more than 8 correct solutions, give a complementary comment. For less than 6 correct solutions, give an encouragement statement. Note that the user should only have one chance to answer each question.
 (b) Modify the program as `frandomaddsubmul.ch` to select a random operation of addition, subtraction, or multiplication.
8. Write a program `plotcircle.ch` to generate Figure 3.2 in Chapter 3. You may zoom in on a point in the circle to find the x and y coordinates first, then draw the radial line with an arrow.
9. Modify the program `robotpos3.ch` developed in Exercise 12 in Chapter 5 to use a function `position()` with the prototype

```
double position(double t)
```

to calculate the robot position. Plot the robot position versus time using the member function `plot.func2D()`.

10. The graph of $y = x^2 + k$ is a vertical shift of $y = x^2$ by k units. If $k > 0$, the shift is upward. If $k < 0$, the shift is downward. Write a program `shift.ch` to plot the equations $y = x^2 + 2$, $y = x^2$, and $y = x^2 - 3$, as shown in Figure 7.11. The graph for $y = x^2 + 2$ is 2 units above the graph for $y = x^2$. The graph for $y = x^2 - 3$ is 3 units below the graph for $y = x^2$.

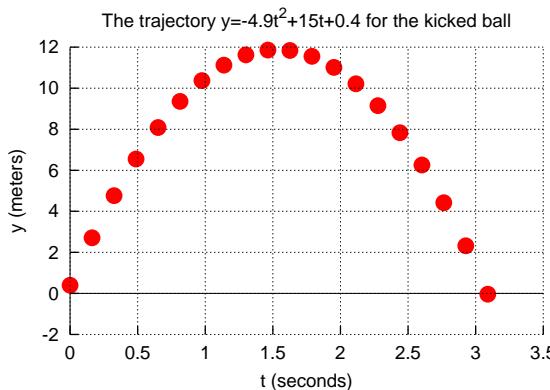
7.9. Exercises

Figure 7.11: The graphs for $y = x^2 + 2$, $y = x^2$, and $y = x^2 - 3$.

11. When a soccer ball is kicked from a platform 0.4 meter above the ground with an initial velocity of 15 m/sec, the height of the ball in meters can be modeled by the equation

$$y = -4.9t^2 + 15t + 0.4$$

where t is the time in seconds. Write a computer program `soccer.ch` to plot the trajectory as a scatter plot with 20 points for time t from 0 to 3.09 seconds for the soccer as shown in Figure 7.12

Figure 7.12: The trajectory for the soccer ball modeled by the equation $y = -4.9t^2 + 15t + 0.4$.

12. Based on the information from the American Speech-Language Hearing Association, the number N , in millions, of hearing-impaired Americans of age x can be approximated by the cubic polynomial equation

$$N = -0.00006x^3 + 0.006x^2 - 0.1x + 1.9 \quad (7.8)$$

Write a program `hearing.ch` to plot the equation for x from 0 to 84.74, as shown in Figure 7.13.

7.9. Exercises

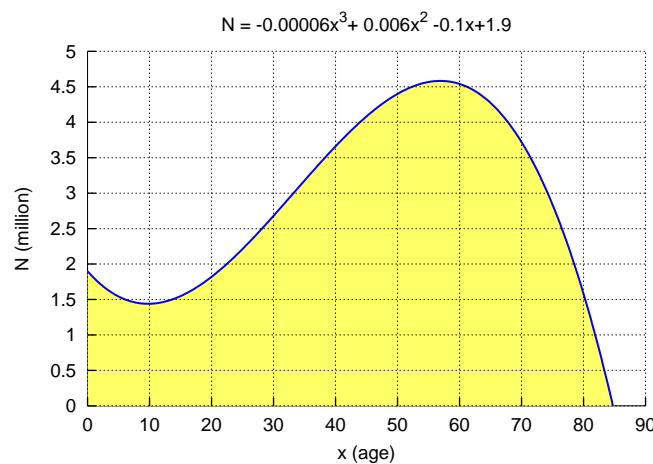
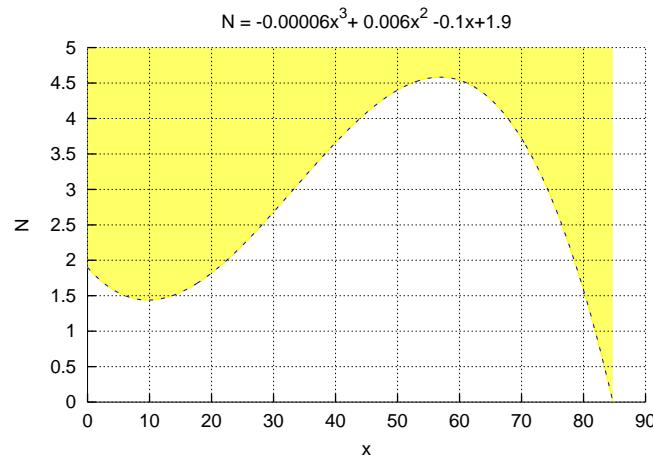


Figure 7.13: Hearing-impaired Americans at different ages.

13. Modify the program `hearing.ch` developed in Exercise 13 as a program `hearing2.ch`. The program generates a plot shown below.



14. Write a program `rectangle.ch` to read the values for the height and width of a rectangle using two variables of **double** type. Calculate the area and perimeter of the rectangle using the function `func()` as shown in the code below. Print these values in the program.

```
/* function prototype */
void func(double h, double w, double &a, double &p) {
    /* (add code here) */
}

double height, width, area, perimeter; // declare variables
/* (add code here) obtain the user input values for height and width */
func(height, width, area, perimeter); // call the func()
/* (add code here) print out area and perimeter */
/* (add code here) define the function func() */
```

15. ‡ Write a program `quadratic1.ch` using the Ch function `quadratic()` to solve the following quadratic equations.

7.9. Exercises

$$(i) x^2 - 5x + 6 = 0 \quad (ii) x^2 - 5x + 6.25 = 0 \quad (iii) x^2 + -x + 7.25 = 0$$

Print the discriminant and roots for each of these equations similar to the one shown below.

equation	discriminant	x1	x2
$x^2 - 5x - 6 = 0$	9.00	1.00	4.00
...			

16. ‡ A quadratic equation contains a second-degree polynomial in the form of

$$y = ax^2 + bx + c \quad (7.9)$$

with $a \neq 0$. Graphs of quadratic equations are called *parabolas*. As shown in Figure 7.14 of the polynomial equation $y = x^2 - 5x + 6$, graphs of quadratic equations $y = ax^2 + bx + c$ are smooth cup-shaped symmetric curves. The top or bottom point where the curve changes direction is called the *vertex*. If $a > 0$, the curve opens up and the y -coordinate of the vertex is the minimum value of y . If $a < 0$, it opens down and the y -coordinate of the vertex is the maximum value of y . The x -coordinate of the vertex is

$$x = -\frac{b}{2a} \quad (7.10)$$

The y -coordinate of the vertex can be found by substituting the x -coordinate into the equation and solving for y . The vertex (x, y) of a parabola can be obtained by the Ch built-in function **vertex()** with the following function prototype.

```
void vertex(double a, double b, double c, double &x, double &y)
```

where the arguments a , b , and c are the coefficients of the polynomial, and x and y are the vertex passed by reference. Write a program **polynomialvertex.ch** to calculate the vertex using the Ch function **vertex()**, and plot the polynomial $y = x^2 - 5x + 6$ and vertex as shown in Figure 7.14.

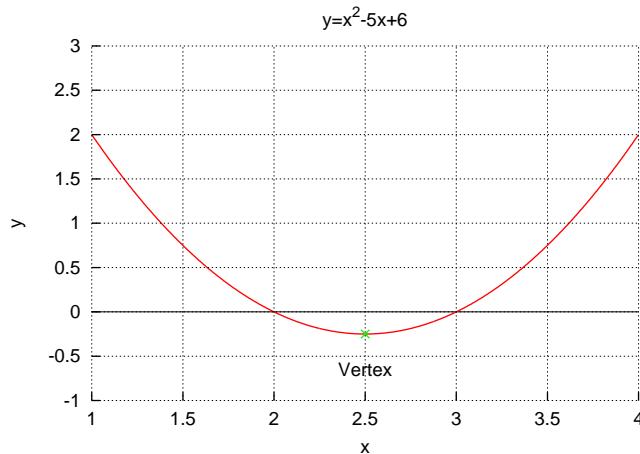


Figure 7.14: The graph for the polynomial equation $y = x^2 - 5x + 6$ with a vertex.

17. ‡ Write programs **g1.ch**, **g2.ch**, **g3.ch**, and **g4.ch** to calculate the values of the following functions using a C function for each one at $x = 3.5$.

$$(a) g_1(x) = 2x \sin(x) + \cos(x) + \frac{4x + 3}{3x^2 + 2x + 4}$$

$$(b) g_2(x) = x^2 \sqrt{2x}$$

$$(c) g_3(x) = 2x \sin(x) + \cos(x^2 \sqrt{2x})$$

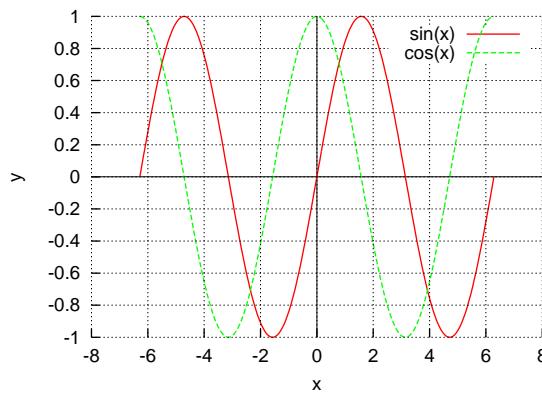
7.9. Exercises

$$(d) \ g_4(x) = \frac{3x^2 + 4x + 3}{5 \sin(x^2) + 4x^2 + 3}$$

18. ‡ Write a program `sincos.ch` to plot the following functions

$$\begin{aligned} f_1(x) &= \sin(x) \\ f_2(x) &= \cos(x) \end{aligned}$$

for x from -2π to 2π , with the figure shown below.



CHAPTER 8

Arrays for Data Processing

Arrays are commonly used programming features for computation with large sets of data in engineering and science. An **array** is a data structure consisting of a group of related data items. All elements in an array have the same name and data type. An **array** consists of elements that extend in one or more dimensions to represent columns, planes, cubes, etc. Arrays in a program can be used to represent vectors and matrices in mathematics.

Arrays are an easy way of storing a group of data under one name. For example if we want to store the results for Julio's last six quizzes we could create an array to hold integers for the quiz scores. To make it easy to recognize we will name the array `quizGrade`

```
array int quizGrade[6];
```

This creates a space in memory to hold 6 integer values that we can specify later. In this chapter, arrays and their applications are presented.

8.1 Declaration, Reference, Input, and Output for Arrays

Prerequisite: Understanding advanced variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.3, D5.5

Objective: Write computer code to initialize and assign values to an array variable.

8.1. Declaration, Reference, Input, and Output for Arrays

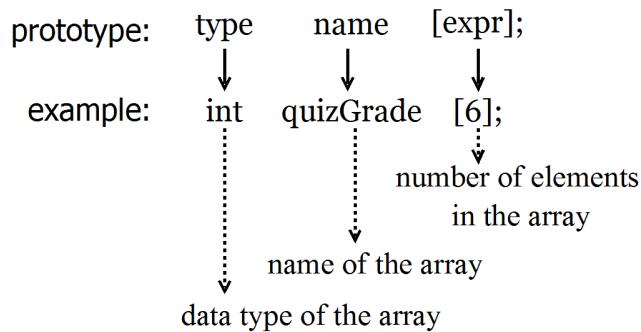


Figure 8.1: A general format for declaring an array and an example.

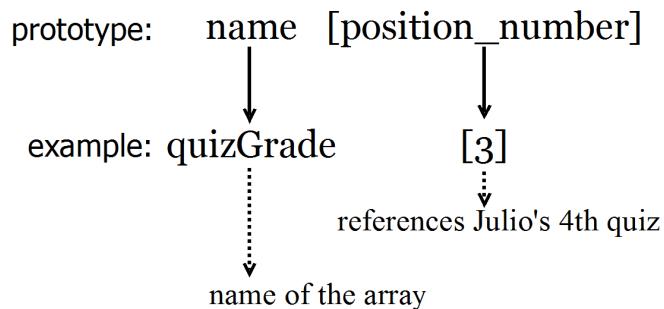


Figure 8.2: A general format for referring an element in an array and an example.

A general format for declaring an array with an example is shown in Figure 8.1. The format for declaration is as follows.

```
array type name [expr];
```

where the symbol **array** is a keyword for array, the symbol **type** can be **int** or **double**. The symbol **name** is an identifier. The number of elements in the declared array is specified in the **expr** inside a pair of brackets.

A general format for referring an element in an array and an example is shown in Figure 8.2. The elements of an array can be referred by the following format,

```
name [position_number]
```

where **position_number** is the position of array element. The **position_number** is also called an **index**. Note that the first element of an array is by default at position 0. In our example the six elements can be represented as `quizGrade[0]`, `quizGrade[1]`, `quizGrade[2]`, `quizGrade[3]`, `quizGrade[4]`, and `quizGrade[5]`.

Example In the example below we will declare an integer array `quizGrade` with 6 elements and then initialize the first element in a Ch Command Shell. We will then use that value to initialize the last element.

```
> array int quizGrade[6] // declare array quizGrade with 6 int elements
> quizGrade[0]=10 // initialize the first element as 10
```

8.2. How Arrays Are Stored in Memory

```
> quizGrade[5]=2*quizGrade[0] // initialize the last element
   // as twice the first element
```

The input and output for an element in an array can be treated as if it is a simple variable as shown below.

```
> scanf("%d", &quizGrade[2])
95
> printf("quizGrade[2] = %d", quizGrade[2])
quizGrade[2] = 95
```

 Do Exercises 1(a) and 2 one page 162.

8.2 How Arrays Are Stored in Memory

Prerequisite: Understanding advanced variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.3, D5.5

Objective: Understand how the structure of an array is implemented in computer memory.

When an array is declared, memory is automatically allocated. Arrays are grouped in consecutive memory locations. For example, a sample memory layout for the array `a` of six elements of `int` type declared below

```
array int a[6];
```

is shown in Figure 8.3.

8.3. Initialization of Arrays

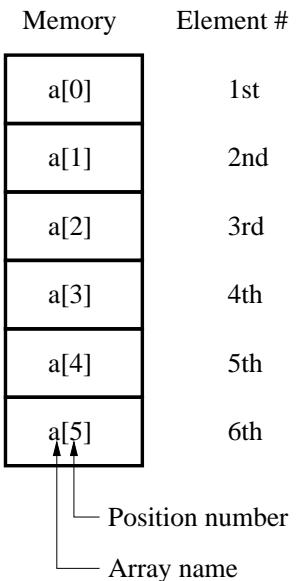


Figure 8.3: An array and its layout in the memory.

8.3 Initialization of Arrays

Prerequisite: Understanding advanced variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.3, D5.5

Objective: Write computer code to initialize and assign values to array variable.

A general format for initializing an array and an example is shown in Figure 8.4. Arrays are initialized with values within a pair of braces “{ }” placed after the assignment operator “=” in the form of

```
array type name[expr] = {initializers};
```

where expr shall be a positive integer.

8.4. Debugging Programs with Arrays

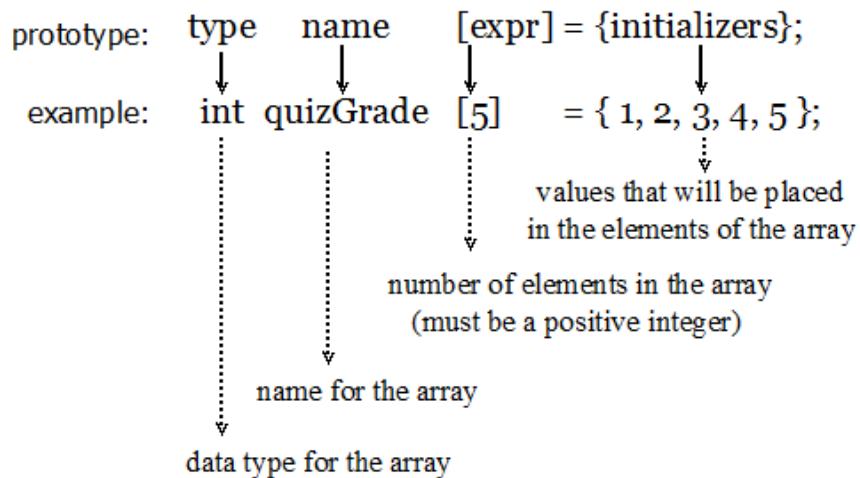


Figure 8.4: A general format for initializing an array and an example.

For example, the statement

```
array int a[5] = {1, 2, 3, 4, 5};
```

initializes integer array a such that $a[0] = 1$, $a[1] = 2$, etc. If too few initializers are specified, then the rightmost elements are initialized to 0. For example, for

```
array int a[5] = {1, 2, 3};
```

elements $a[3]$ and $a[4]$ are 0. If there are too many specifiers, then a syntax error will result. To initialize all the elements of an array to 0, the following statement can be used.

```
array int a[5] = {0};
```

which sets all elements without initializers to 0.

Furthermore, an array can also be initialized without specifying the array size. In this case, the number of initializers is used to determine the size of the array. For example,

```
array double a[] = {1, 2, 3, 4, 5};
```

would initialize a five-element array of **double** type. The array a is an incomplete type and is completed at initialization.

Do Exercises 1(b) and 3 one page 162.

8.4 Debugging Programs with Arrays

Prerequisite: Understanding advanced variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.3, D5.5

Objective: Use the ChIDE debugger to view how the contents of an array variable change during execution of the program.

8.5. Processing Data in Arrays

```

/* File: sum.ch
   Calculate the sum for elements in an array */
#define N 8 /* number of elements for array a */
/* declare array a with initialization */
array double a[N] = {3.0, 21.0, 0.0, -3.0, 34.0, -14.0, 45.0, 18.0};
double sum;           // sum of all elements of array
int i;                // variable for array index

/* add all elements of array using a for-loop */
sum = 0.0;            // initialize the variable sum
/* loop through the entire array starting with the first element */
for(i= 0; i < N; i++) {
    sum = sum + a[i]; // add each element to sum
}

printf("The sum for elements in the array is %lf\n", sum);

```

Program 8.1: Calculating the sum for elements in an array.

In the program `sum.ch` listed in Program 8.1, the array `a` contains 8 elements. Because the data is saved in an array, it can be easily processed using a loop. In Program 8.1, the macro `N` is defined as 8. The variable `sum` is initialized to 0 before the loop starts. The values of elements in the array are added together and stored in the variable `sum` using a `for` loop. When the program is executed, it will display the following output:

The sum for elements in the array is 104.000000

The method for debugging programs, described in sections 2.4 and 7.2, is also applicable to programs with arrays. As an example, open the program `sum.ch`. Next, click the command `Step`. Then, select the menu `Locals or Variables` on the debugging pane selection bar, as shown in Figure 2.4. For a variable of array type, each element of the array will be displayed. When an element of an array is modified, the entire array will be updated when the array is displayed. Finally, you can click several times for the command `Step` and observe how the array changes.

 Do Exercise 4 on page 163.

8.5 Processing Data in Arrays

Prerequisite: Understanding advanced variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.3, D5.5

Objective: Write computer code to initialize and assign values to array variable and process the data in the array to find the mean, minimum/maximum values, and sum of the data.

8.5. Processing Data in Arrays

An element of an array can be read and modified at runtime based on its index. Elements of an array are typically processed using loops. In this section, how data in an array can be processed will be illustrated by three examples. The first example calculates the mean value for elements of an array. The second example finds the minimum value in an array. It illustrates how to search a certain value in a database. The third example re-writes a previously written program using an array allowing the program to be easily modified to solve other similar problems.

Mean

The **mean** or **average** value is defined as the sum of all elements divided by the number of elements. The equation for calculation of the mean value for n elements is as follows.

$$\mu = \frac{x_1 + x_2 + \dots + x_n}{n}$$

For example, given the set of values 3, 21, 0, -3, 34, -14, 45, 18 to find the mean, you would first add all of the values:

$$3 + 21 + 0 + (-3) + 34 + (-14) + 45 + 18$$

then divide the result by the number of values you have; in this case 8.

```
/* File: mean.ch
   Calculate the mean value for elements in an array */

#define N 8 /* number of elements for array a */

/* declare array a with initialization */
array double a[N] = {3.0, 21.0, 0.0, -3.0, 34.0, -14.0, 45.0, 18.0};
double sum,          /* sum of all elements of array */
       meanval; /* mean value for all elements of array */
int i;              /* variable for array index */

/* add all elements of arary using a for-loop */
sum = 0.0;           /* initialize the variable sum */
/* loop through the entire array starting with the first element */
for(i= 0; i < N; i++) {
    sum = sum + a[i];      /* add each element to sum */
}

/* calculate the mean value. */
meanval = sum / N;
printf("The mean value of elements in the array is %lf\n", meanval);
```

Program 8.2: Calculating the mean value for elements in an array.

Program 8.2 illustrates how the mean value for elements in array a is calculated. The variable sum is first set to zero. A **for** loop is then used to add all eight elements from $a[0]$ to $a[N-1]$ with the macro N defined as 8. The variable $meanval$ contains the mean value. The output of Program 8.2 is given below.

```
The mean value of elements in the array is 13.000000
```

8.5. Processing Data in Arrays

```

/* File: minimum.ch
   Find the minimum value in an array */

#define N 8    /* number of elements for array a */

/* declare array a with initialization */
array double a[N] = {3.0, 21.0, 0.0, -3.0, 34.0, -14.0, 45.0, 18.0};
double minval; /* minimum value */
int i;          /* variable for array index */

minval = a[0]; /* initialize to the first element */
/* loop through the array starting with the second element */
for(i= 1; i < N; i++) {
    if(a[i] < minval) { /* if a[i] < minval, set new minval */
        minval = a[i];
    }
}
printf("The minimum value of the array is %lf\n", minval);

```

Program 8.3: Finding the minimum value for elements in an array.

Minimum and Maximum

Program 8.3 finds the minimum value in array `a`. The variable `minval` is first assigned with the value of the first element `a[0]` of the array. It is then compared with all other elements one by one in a `for` loop. The index variable `i` for the loop starts with 1 allowing the first element to be compared with the second element `a[1]` in the first iteration. If the value for a new element is smaller than the value saved in the variable `minval`, the value for the new element will be assigned to the variable `minval` by the `if` statement.

```

if(a[i] < minval) { /* if a[i] < minval, set a new minval */
    minval = a[i];
}

```

At the end of iteration, the variable `minval` contains the minimum value of the array. If there are multiple copies of the minimum value in the array, `minval` contains the first minimum value of the array. The output of Program 8.3 is given below.

```
The minimum value of the array is -14.000000
```

To find the maximum value in an array, the conditional expression of the `if` statement in Program 8.3

```
a[i] < minval
```

needs to be changed to

```
a[i] > maxval
```

 Do Exercise 5 on page 163.

Application: Random Number Generation: Rolling a Six-Sided Die**Problem Statement:**

Simulate the rolling of a six-sided die 6,000 times and record the number of times it falls on each face.

8.5. Processing Data in Arrays

Program 6.9 in Chapter 6 simulates the rolling of a six-sided die 6,000 times and records the number of times it falls on each face. The frequency for each face is stored in a variable. Six variables freq1 to freq6 are used for six different faces. Program 6.9 can be modified to use a single variable of array type for frequencies of six different faces. Program 8.4 uses a six-element array freq as a counter for each face of the die. Using the variable face as an array index for array freq, the **if** statement in Program 6.9 is replaced by a single assignment expression statement

```
freq[face-1] = freq[face-1] + 1;
```

Because the array elements are from freq[0] to freq[5], whereas the values for variable face ranges from 1 to 6, the index of the array is offset by 1. Using an array, the frequency for each face can be printed using a loop conveniently. The macro N defines the number of sides of a die. The program can be used to simulate the rolling of a die with a different number of faces by changing only the value of this macro. For alignment of the output, the conversion specifier with a field width of 12 is used to print the string "Frequency" by the statement.

```
printf("%s%12s\n", "Face", "Frequency");
```

The field widths of 2 and 12 are used for the face and counters for each face of the die using the statement.

```
printf(" %2d%12d\n", face, freq[face-1]);
```

```
/* File: sranda.ch
   Roll a six-sided die 6,000 times randomly,
   calculate the frequencies for each face.
   Use an array to keep frequency for each face */

#define N 6           /* the number of sides of a die */

int face,           /* face in each roll */
     trial;          /* roll count number */
array int freq[N]={0}; /* array of frequencies for each face,
                           initialize each element with 0 */

/* use a loop to roll N*1,000 times */
for(trial = 1; trial <= N*1000; trial++) {
    face = randint(1, N); /* generate a random number in [1, N] */
    /* the corresponding frequency for the face is incremented.
       array index for freq[] ranges from 0 to N-1 */
    freq[face-1] = freq[face-1] + 1;
}

/* display the result */
printf("%s%12s\n", "Face", "Frequency");
for(face = 1; face <= N; face++) {
    printf(" %2d%12d\n", face, freq[face-1]);
}
```

Program 8.4: Rolling a six-sided die 6,000 times using an array.

Since Programs 6.9 and 8.4 are supposed to simulate the random rolling of the die 6,000 times, the output of either program will be different for every program execution. The result of one run-time execution of Program 8.4 is shown below.

8.6. Passing Arrays to Functions

Face	Frequency
1	978
2	1060
3	972
4	1028
5	962
6	1000

 Do Exercises 6, 7, and 8 on page 163.

8.6 Passing Arrays to Functions

Prerequisite: Understanding advanced variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.3, D5.5

Objective: Differentiate the behavior of array variables against non-array variables when passed to a function.

A function can be used to process data in different arrays. A general function prototype for a function with an argument of array is as follows.

```
return_type functionName(int n, array type arrayName[]);
```

where `return_type` is the function return type, `functionName` is the function name. The first argument `n` is the number of elements of an array passed to the function through the second argument `arrayName` with the data type specified by `type`. The function can be called in a calling function by

```
functionName(n, arrayName);
```

For example, if the function `sum()` has the following prototype,

```
double sum(int n, array double a[]); // function prototype
```

it can be called in a calling function as follows.

```
array double a[12];
double total;
total = sum(12, a);           // calling the function
```

As an application example, the grades for students in two classes A and B are listed in Table 8.1. Class A has 12 students and class B has 14 students.

8.6. Passing Arrays to Functions

```

/* File: classaverage.ch
Calculate the class average grade for classes A and B
with grades stored in arrays using a function sum() */

#define N1 12          // number of students in class A
#define N2 14          // number of students in class B

double sum(int n, array double a[]) {
    double s;        // sum of all elements of the array
    int i;           // variable for array index

    /* add all elements of the array using a for-loop */
    s = 0;           // initialize the variable s
    /* loop through the entire array starting with the first element */
    for(i= 0; i < n; i++) {
        s = s + a[i]; // add each element to s
    }
    return s;
}

/* grades for class A */
array double gradesA[N1] = {81, 98, 100, 73, 87, 92, 98, 87, 99, 98, 76, 91};
/* grades for class B */
array double gradesB[N2] = {91, 88, 93, 77, 80, 82, 88, 87, 89, 98, 86, 81, 82, 83};
double average;

average = sum(N1, gradesA)/N1;
printf("The class average grade for class A is %.1f\n", average);
average = sum(N2, gradesB)/N2;
printf("The class average grade for class B is %.1f\n", average);

```

Program 8.5: Passing arrays to a function to calculate the class averages.

8.7. Plotting Data in Arrays for Graphical Display

Table 8.1: The grades for students in classes A and B.

class	grades													
class A	81	98	100	73	87	92	98	87	99	98	76	91		
class B	91	88	93	77	80	82	88	87	89	98	86	81	82	83

Program 8.5 finds the class average grades for these two classes. The **class average** is the result of the sum of grades for each student in a class dividing by the number of students. The grades for 12 students in class A are stored in the array `gradesA` with 12 elements. The macro `N1` for 12 defines the number of students in class A. The macro `N2` is for the number of students in class B. The grades for 14 students in class B are in the array `gradesB`. The function `sum()` with the function prototype

```
double sum(int n, array double a[])
```

is used to find the sum of all elements for array `a` passed through the second argument. The statement

```
average = sum(N1, gradesA)/N1;
```

calculates the class average for class A. The similar statement

```
average = sum(N2, gradesB)/N2;
```

calculates the class average for class B. The code inside the function `sum()` is similar to the code in Program 8.1. The first argument is the number of elements of the passed array. The function uses a **for** loop to obtain the sum for all elements of the passed array. The function returns the sum in the variable `s`. The output from executing Program 8.5 is as follows.

```
The class average grade for class A is 90.0
The class average grade for class B is 86.1
```

 Do Exercises 9 and 10 on page 163.

8.7 Plotting Data in Arrays for Graphical Display

Prerequisite: Understanding advanced variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1, D5.3, D5.5

Objective: Write computer code to initialize and assign values to array variables and pass those arrays into the **CPlot** member functions to produce curves, scatter plots, trend lines, and other graphical displays of the data.

Section 7.5 in Chapter 7 describes how to use the member function **func2D()** of the plotting class **CPlot** to plot functions. However, in some applications such as data acquisition, we may need to visualize the experimental results by plotting data in arrays. In this section, we will introduce member functions to plot data in arrays.

8.7. Plotting Data in Arrays for Graphical Display

8.7.1 Plotting a Curve Using the Member Function `data2DCurve()`

The member function `data2DCurve()` of the plotting class `CPlot` can be used to plot data in arrays in the form

```
plot.data2DCurve(x, y, n);
```

The array `x` stores data for the x-axis, whereas the array `y` stores data for the y-axis. Both arrays `x` and `y` shall have the same number of elements, which is specified by the third argument `n` of integral value.

Application: Plotting Positions of a Robot**Problem Statement:**

The time and corresponding positions of a robot are recorded in Table 8.2 in an experiment. Write a program to plot the trajectory of the robot based on the data in this table.

Table 8.2: Positions of a robot versus time.

time (seconds)	0.00	2.00	4.00	6.00	8.00	10.00
position (meters)	1.25	1.75	2.25	2.75	3.25	3.75

```
/* File: posplota.ch
   Plot the positions of a robot versus time for 6 points of data in arrays */
#include <chplot.h>      /* for the function plotxy() */
#define N      6           /* number of plotting points */

/* data for plotting */
array double t[N] = {0.00, 2.00, 4.00, 6.00, 8.00, 10.00 };
array double p[N] = {55.00, 23.00, 7.00, 7.00, 23.00, 55.00};
CPlot plot;

plot.title("Position Plot");
plot.label(PLOT_AXIS_X, "time (seconds)");
plot.label(PLOT_AXIS_Y, "position (meters)");
plot.data2DCurve(t, p, N);
plot.plotting();
```

Program 8.6: Plotting positions versus time for motion of a robot using arrays.

Program 8.6 uses the member function `data2DCurve()` to plot the position of the robot with 6 data points. The output plot is the same as the one shown in Figure 7.4 in Chapter 7. In Program 8.6, the array `t` contains the time and array `p` with the positions.

 Do Exercise 11 on page 163

8.7. Plotting Data in Arrays for Graphical Display

8.7.2 Plotting Points for Scatter Plots and Trend Lines

A **scatter plot** is a graph with points to show a possible relation between two sets of data. It can be used effectively to show some trends.

The member function **scatter()** of the plotting class **CPlot** can be used to plot data in arrays in the form

```
plot.scatter(x, y, n);
```

as a scatter plot. Similar to the member function **data2DCurve()**, the array **x** stores data for the x-axis, whereas the array **y** stores data for the y-axis. Both arrays **x** and **y** shall have the same number of elements, which is specified by the third argument **n** of integral value.

For example, based on the formula

$$p(t) = 0.25t + 1.25$$

for motion of a robot, two sets of data, time and position, are recorded. These two data sets are stored in the arrays **t** for time in seconds and **p** for position in meters. Program 8.7 plots the data using the member function **plot.plotType()** as a scatter plot. The graph clearly shows the linear relation between the time and position for the motion of the robot.

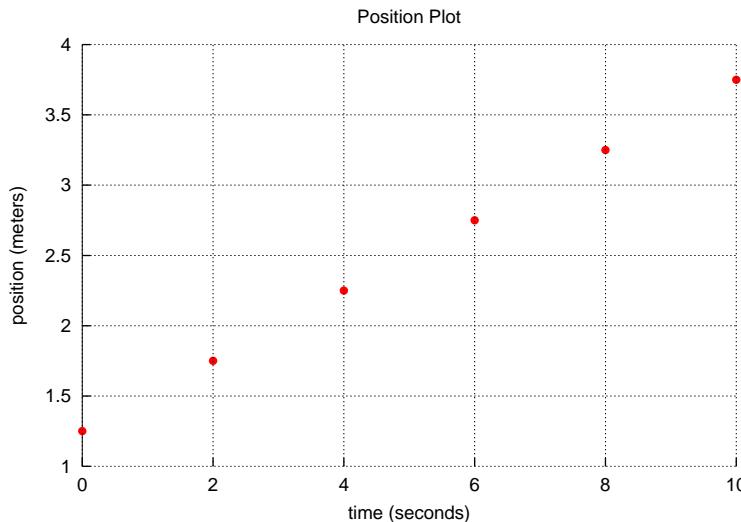


Figure 8.5: A trend plot for the position versus time for motion of a robot, generated by Program 8.7.

8.7. Plotting Data in Arrays for Graphical Display

```

/* File: posplotpoints.ch
   Plot the position versus time with 6 points */
#include <chplot.h>      /* for class CPlot for plotting */
#define N      6           /* num of points for the curve */

/* declare two sets of arrays for plotting for p versus t */
array double t[N] = {0.00, 2.00, 4.00, 6.00, 8.00, 10.00};
array double p[N] = {1.25, 1.75, 2.25, 2.75, 3.25, 3.75};
CPlot plot;
int datanum=0;

/* use a plotting class to plot two curves on the same figure */
plot.title("Position Plot");           // set the title of the plot
plot.label(PLOT_AXIS_X, "time (seconds)"); // set the label on the x-axis
plot.label(PLOT_AXIS_Y, "position (meters)"); // set the label on the y-axis
plot.scatter(t, p, N);    // add data t[] and p[] for scatter plot
plot.plotting();           // plot and display it

```

Program 8.7: Plotting positions in points using arrays.

 Do Exercise 12 on page 164.

We can also write a program to plot a scatter plot by entering data points interactively. When Program 8.8 is executed, the user will input the title, x-label, and y-label of the plot first. Next, enter the number of points for a scatter plot. Then input the x and y coordinates for each point separated by a space. Once the data is inputted, a scatter plot will be displayed. A sample interactive execution of the program is shown below.

```

Welcome to the Scatter Plotter!
Please input the title of the plot
Position Plot
Please input the xlabel of the plot
time (s)
Please input the ylabel of the plot
position (m)
Please input the number of points
6
Please input 5 points (ex. 1 2 for x1 y1)
0 1.25 2 1.75 4 2.25 6 2.75 8 3.25 10 3.75

```

With 6 data points, a graph, the same as the one shown in Figure 8.5, will be displayed.

In Program 8.8, arrays `x` and `y` are declared by the statement

```
array double x[n], y[n]; // data points for (x, y)
```

The value for `n` is obtained from the user input through the function `scanf()`. Because the number of elements of arrays `x` and `y` are determined at the runtime, arrays `x` and `y` are called **variable length arrays**. A `for` loop is used to fill each element of arrays `x` and `y` with a value from the user with

```

for(i=0; i<n; i++) {
    scanf("%lf%lf", &x[i], &y[i]);
}

```

 Do Exercises 13 on page 164.

8.7. Plotting Data in Arrays for Graphical Display

```

/* File: scatterplot2.ch
   Plot a scatter plot with data points from the user input. */
#include <chplot.h>      /* for class CPlot for plotting */
#define N 100          // string length
CPlot plot;
int datanum = 0;    // the number of data set
int i, n;           // the number of data points
string_t title;     // the title of the plot
string_t xlabel;    // the x label of the plot
string_t ylabel;    // the y label of the plot

printf("Welcome to the Scatter Plotter!\n");
/* get title, xlabel, and ylabel */
printf("Please input the title of the plot\n");
scanf("%s", &title);
printf("Please input the xlabel of the plot\n");
scanf("%s", &xlabel);
printf("Please input the ylabel of the plot\n");
scanf("%s", &ylabel);

/* get the number of points and their coordinates using arrays and a for-loop */
printf("Please input the number of points\n");
scanf("%d", &n);
array double x[n], y[n]; // declare arrays x and y for data points for (x, y)
printf("Please input %d points (ex. 1 2 for x1 y1)\n", n);
for (i=0; i<n; i++) {
    scanf("%lf%lf", &x[i], &y[i]);
}

/* plotting a scatter plot */
plot.title(title);           // set the title of the plot
plot.label(PLOT_AXIS_X, xlabel); // set the label on the x-axis
plot.label(PLOT_AXIS_Y, ylabel); // set the label on the y-axis
plot.scatter(x, y, n);      // add data x[] and y[] for scatter plot
plot.plotting();             // plot and display it

```

Program 8.8: A program for plotting scatter plots interactively.

8.7. Plotting Data in Arrays for Graphical Display

```

/* File: posdata2DCurve.ch
   Plot the position versus time with 6 and 21 points on the same figure */
#include <chplot.h>      /* for class CPlot for plotting */
#define N1    6           /* num of points for the 1st curve */
#define N2    21          /* num of points for the 2nd curve */

/* declare two sets of arrays for plotting for p versus t */
array double t1[N1] = {0.00, 2.00, 4.00, 6.00, 8.00, 10.00 };
array double p1[N1] = {55.00, 23.00, 7.00, 7.00, 23.00, 55.00};
array double t2[N2] = {0.00, 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 3.50,
                      4.00, 4.50, 5.00, 5.50, 6.00, 6.50, 7.00, 7.50,
                      8.00, 8.50, 9.00, 9.50, 10.00};
array double p2[N2] = {55.00, 45.50, 37.00, 29.50, 23.00, 17.50, 13.00,
                      9.50, 7.00, 5.50, 5.00, 5.50, 7.00, 9.50, 13.00,
                      17.50, 23.00, 29.50, 37.00, 45.50, 55.00};

CPlot plot;
int datanum;           // number of plotting data set

/* use a plotting class to plot two curves on the same figure */
plot.title("Position Plot");           // set the title of the plot
plot.label(PLOT_AXIS_X, "time (seconds)"); // set the label on the x-axis
plot.label(PLOT_AXIS_Y, "position (meters)"); // set the label on the y-axis
plot.data2DCurve(t1, p1, N1); // add data p1[] and t1[] for the 1st curve
plot.legend("6 points", datanum); // set the legend for the 1st curve
plot.data2DCurve(t2, p2, N2); // add data p2[] and t2[] for the 2nd curve
datanum++;
plot.legend("21 points", datanum); // set the legend for the 2nd curve
plot.plotting();                  // plot and display it

```

Program 8.9: Plotting two position curves in a single plot with data in arrays.

8.7.3 Plotting Multiple Curves in Different Arrays in a Single Plot

Multiple sets of data stored in arrays can be added to the plot by using the member function **plot.data2DCurve()**. For example, Program 8.9 plots two position curves with data stored in arrays. Arrays **t1** and **p1** contain 6 points of data for time and position, respectively. Arrays **t2** and **p2** have 21 elements. Similar to Program 7.7, a legend for each curve is added by the member function **plot.legend()**. The plot generated by Program 8.9 is the same as the one shown in Figure 7.6.

 Do Exercise 14 on page 164.

The member function **plot.data2DCurve()** can also be used to draw polygons. For example, Program 8.10 draws two polygons shown in Figure 8.6. The vertices of the first diamond shaped polygon are stored in arrays **x1** and **y1**. The vertices of the triangle are in arrays **x2** and **y2**. Three vertices A, B, and C of the triangle are labeled by calling the member function **plot.text()** three times.

 Do Exercises 15, and 16 on page 164.

8.7. Plotting Data in Arrays for Graphical Display

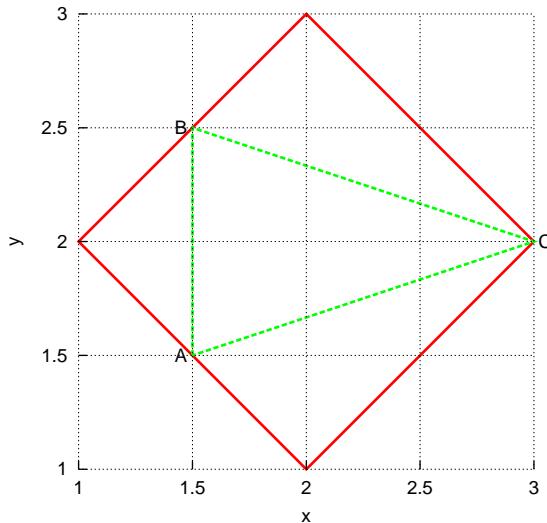


Figure 8.6: Two polygons generated by Program 8.10.

```
/* File: polygon.ch
   Draw polygons and texts */
#include <chplot.h>
CPLOT plot;
array double x1[5] = {3, 2, 1, 2, 3}, y1[5] = {2, 3, 2, 1, 2};
array double x2[4] = {1.5, 1.5, 3, 1.5}, y2[4] = {1.5, 2.5, 2, 1.5};

/* set the plot size ratio */
plot.sizeRatio(1);

plot.data2DCurve(x1, y1, 5); /* draw a diamond */
plot.data2DCurve(x2, y2, 4); /* draw a triangle */

/* draw texts A, B, C */
plot.text("A", PLOT_TEXT_CENTER, 1.45, 1.5, 0);
plot.text("B", PLOT_TEXT_CENTER, 1.45, 2.5, 0);
plot.text("C", PLOT_TEXT_CENTER, 3.05, 2.0, 0);
plot.plotting();
```

Program 8.10: Drawing polygons on a plot.

8.8 Chapter Summary

8.8.1 Programming Tips

Common Programming Errors

- Access an array outside its boundary by subtracting one from the term number. For example,

```
array int a[4];      // four elements are a[0], a[1], a[2], a[3]
a[4] = 10;          // bad
```

8.8.2 Terminology

General Concepts

array	average	index
	maximum	mean
minimum		

Ch Reserved Words

[]

The Plotting Class CPlot

CPlot::data2DCurve() CPlot::plotType() CPlot::scatter()

8.9 Exercises

- Find the error(s) in each of the following program segments, and explain how each error can be fixed.

```
(a) array int a[3];
printf("%d %d %d\n", a[1], a[2], a[3]);
(b) array double f[3] = {1.1, 10.01, 100.001, 1000.001};
```

- Declare array a with 10 elements of **double** type in a Ch Command Shell first. Then, perform the following operations

```
a[0] = 2.4
a[9] = 5
a[2] = 2*a[0] + a[9]
```

If you type a[-1], a[11], and a[10], what are the results? If there are error messages, explain the reason briefly.

- Declare an array b with a proper number of elements and initialize the array with the following numbers for its elements in a Ch Command Shell first.

1 2 3 4 5 6.5

Then, perform the following operations

```
b[3] = b[1] + b[2]
```

8.9. Exercises

4. Given a set of data below

```
1 2 3 4 5 6 7 8 9 10 11 12
```

write a program `sum2.ch` to store the data in an array of double type. Add numbers in the array using a **for** loop and display the sum of these data on the screen. Use the command Step or Next to run `sum2.ch` in ChIDE.

5. Given a set of data below

```
3 21 0 -3.5 34 -14 45 18
```

Write a program `maximum.ch` to store these data in an array of double type. Find the maximum value in the array using a **for** loop and display the result on the screen. Use the command Step or Next to run `maximum.ch` in ChIDE.

6. Write a program `rolldie8.ch` to simulate rolling of an eight-sided die 8,000 times and record the number of times it falls on each face.
7. Modify the program `flipcoin.ch` developed in Exercise 27 on page 112 as a new program `flipcoina.ch` to use an array to hold the frequency of heads and tails being rolled.
8. Write a program `rolldie.ch` to simulate rolling of a die. The program receives the user input of the number of sides for the die and the number of rolling, and record the number of times it falls on each face.
9. Based on the algorithm in Program 8.2, write a program `mean2.ch` with the function prototype

```
double mean(int n, array double a[]);
```

to find the mean value of an array passed through the second argument of the function. The first argument contains the number of elements from the passed array. Test the program using an array with the following data.

```
3 21 0 -3.5 34 -14 45 18
```

10. Write a program `range.ch` with two function prototypes

```
double minimum(int n, array double a[]);
double maximum(int n, array double a[]);
```

to find the minimum and maximum of an array passed through the second argument of the function. The first argument contains the number of elements from the passed array. Test the program using an array with the following data.

```
3 21 0 -3.5 34 -14 45 18
```

11. When a soccer ball is kicked on the ground with an initial velocity of 15 m/sec, the height of the ball in meters can be modeled by the equation

$$y = -4.9t^2 + 15t$$

where t is the time in seconds. The time and corresponding positions of the soccer ball are recorded in Table 8.3. Write a program `soccerplot.ch` using the member function `data2DCurve()` to plot the trajectory of the soccer ball based on the data in this table.

Table 8.3: Positions of a soccer ball versus time.

time (seconds)	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3
position (meters)	0	2.8	5.2	7.2	8.9	10.1	10.9	11.4	11.5	11.1	10.4	9.3	7.8	5.9	3.6	0.9

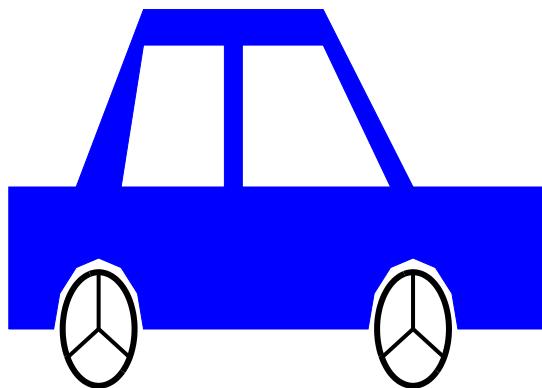
8.9. Exercises

12. Write a program `soccerplotpoints.ch` to create a scatter plot for the soccer problem described in Exercise 11.
13. Create a scatter plot for the soccer problem described in Exercise 11 using the program `scatterplot2.ch` in Program 8.8.
14. For the same soccer ball described in Exercise 11, another set of data is recorded in Table 8.4. Write a program `soccerdata2DCurve.ch` to display the trajectories of the soccer ball with data in both Table 8.3 and Table 8.4 on the same graph.

Table 8.4: Positions of a soccer ball versus time.

time (s)	0	0.5	1	1.5	2	2.5	3
position (m)	0	6.28	10.1	11.47	10.4	6.88	0.90

15. Write a program `polygon2.cpp` to design a graph with at least 10 lines and some text.
16. Plot a car similar to the one shown below.



CHAPTER 9

Working with Data Files

In the previous chapters, data was stored in variables and arrays in main memory for a program. However, once the program terminates, all of the data is lost because the variables and arrays are temporary and only exist during program execution. To overcome this problem, data in a program can be saved into files. In this chapter, we will describe how to use data files for writing, reading, and plotting.

9.1 Writing Data Into Files

Prerequisite: Understanding advanced variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1

Objective: Write computer code to utilize the **FILE** data type and functions **fopen()**, **fprintf()**, **fscanf()**, and **fclose()** to create and populate a data file.

In some applications, the computational results may need to be saved into a file. In this section, the mechanism to write data from a C program into files will be described by solving the following program.

Problem Statement:

The position p of a moving vehicle in meters is expressed as a function of time t as

$$p(t) = 2(t - 5)^2 + 5$$

Write a program to calculate the position from $t = 0$ to $t = 10$ seconds with an incremental step size of 2 seconds and 6 data points in total. Save the values for time and position into a file named `position.txt`.

9.1. Writing Data Into Files

```
/* File: poswrite.ch
   Write the positions versus time for t from 0 to 10 seconds
   with 21 points into file position.txt. */
#define N 6           /* 6 points */
double p, t;          /* data for plotting */
double t0, tf, step; /* time t from t0 to tf with step */
FILE *stream;         /* file streams */

/* open file position.txt for writing */
stream = fopen("position.txt", "w");
if(stream == NULL) {
    printf("Error: cannot open 'position.txt' for writing\n");
    exit(-1);
}

fprintf(stream, "%d\n", N);           // write 7 into the file
t0 = 0.0;
tf = 10.0;
step = 2;
for(t = t0; t <= tf; t = t+step) {
    p = 2*(t-5)*(t-5)+5;
    fprintf(stream, "%lf %lf\n", t, p); // write t and p into the file
}
fclose(stream);                   // close the file stream
printf("Finished writing data to the file position.txt\n");
```

Program 9.1: Writing positions of a moving vehicle into the file position.txt.

```
6
0.000000 55.000000
2.000000 23.000000
4.000000 7.000000
6.000000 7.000000
8.000000 23.000000
10.000000 55.000000
```

Figure 9.1: The contents of the file position.txt as the output from Program 9.1.

Program 9.1 solves the above problem with the data saved in the file position.txt shown in Figure 9.1.

To write data into a file, the file first needs to be opened for writing. The statement

```
FILE *stream;
```

declares a variable `stream` of the data stream type. The built-in data type `FILE` maintains information about the stream.

A general format for opening a file for reading and writing with an example is shown in Figure 9.2. The statement

```
stream = fopen("position.txt", "w");
```

opens the file position.txt for writing. The first argument of the string type of the function `fopen()` is the file name to be opened and associated with a stream. The second argument of the function `fopen()` is the mode for the stream. The string value "`w`" is for writing and "`r`" for reading. In this example, all data is written to the opened file position.txt. The function `fopen()` may fail to open a file. For example, if

9.1. Writing Data Into Files

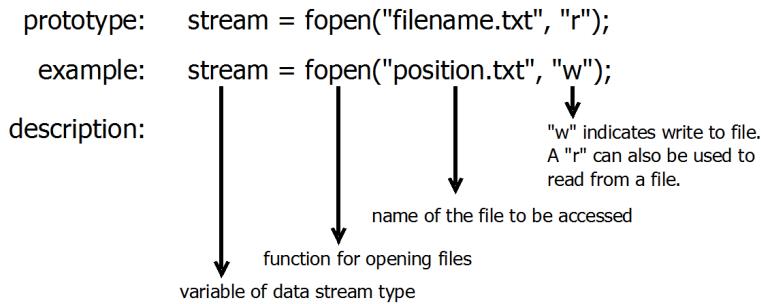


Figure 9.2: A general format for opening a file for reading and writing with an example.

the user does not have a permission to write in a folder where the file will be located, the function `fopen()` will fail. If the function `fopen()` fails to open a file, it will return `NULL`. The macro `NULL` is predefined in Ch. The statement

```
exit(-1);
```

inside the `if` statement block provides an early exit for the program.

The function `fprintf()` can be used to write the data into a file. The function `fprintf()` to be called in the form of

```
fprintf(stream, format, arglist);
```

is similar to the function `printf()` described in section 2.2.1 in Chapter 2. The function `printf()` is called in the form of

```
printf(format, arglist);
```

The first argument of the data stream type of the function `fprintf()` needs to be assigned with a valid value from the function `fopen()` first. Instead of printing the output on the screen, the output from the function `fprintf()` is sent to the file associated with the stream in the first argument. The function call

```
fprintf(stream, "%d\n", N);
```

in Program 9.1 writes the integral value 6 of the macro `N` into the file `position.txt`. The subsequent call of the function `fprintf()` in each iteration of a `for` loop, with an incremental step size of 2 seconds, writes the values `t` for time and `p` for position into the file `position.txt`.

An opened file which is associated with a stream should be closed before the program exits. The function call

```
fclose(stream);
```

in Program 9.1 closes the file `position.txt` associated with the file stream.

A typical structure for writing data into a file is as follows:

```
FILE *stream;
stream = fopen("filename", "w");
if(stream == NULL) {
    printf("Error: cannot open 'filename' for writing\n");
    return -1;
}
fprintf(stream, format, arglist);
fclose(stream);
```

Do Exercise 1 on page 174.

9.2 Reading Data From Files

Prerequisite: Understanding advanced variable types, program structure, arithmetic and relational operators, looping, user-defined functions

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1

Objective: Write computer code to utilize the **FILE** data type and functions **fopen()**, **fscanf()**, and **fclose()** to read data from and write data into a file.

In some applications, data in files may need to be processed. For example, sensory data of an instrument may be saved into a data file first. This way the user may use a program to process the data in the data file later.

A typical structure for reading data from a file is as follows:

```
FILE *stream;
stream = fopen("filename", "r");
if(stream == NULL) {
    printf("Error: cannot open 'filename' for reading\n");
    return -1;
}
fscanf(stream, format, arglist);
fclose(stream);
```

First, the data file `filename` needs to be opened by the function **fopen()**. The second argument "`r`" of the function **fopen()** indicates that the opened stream is for reading. The function **fscanf()** is similar to the function **scanf()** described in section 2.2.2 in Chapter 2. However, instead of reading the data from the keyboard, the function **fscanf()** reads the data from the file `filename` associated with the stream in its first argument.

As an example, Program 9.1 writes the time and positions of a moving vehicle in the data file `position.txt` shown in Figure 9.1. Program 9.2 reads the data for time and position in the data file `position.txt` shown in Figure 9.1, then plots the data as shown in Figure 7.4 in Chapter 7. The statement

```
stream = fopen("position.txt", "r");
```

in Program 9.2 opens the file `position.txt` for reading. The statement

```
fscanf(stream, "%d", &n);
```

reads the first integer value 6 in the file `position.txt` into the variable `n`. The statement

```
double t[n], p[n];
```

declares variable length arrays `t` for time and `p` for position with their sizes determined at the runtime by the value of the variable `n`. The integer value `n` is also the number of iterations for a **for** loop to read the data. Inside the **for** loop, the statement

```
fscanf(stream, "%lf%lf", &t[i], &p[i]);
```

9.2. Reading Data From Files

```

/* File: posreadplot.ch
   Read the positions from file position.txt and plot it */
#include <chplot.h>
CPlot plot;
FILE *stream; /* a file stream */
int i, n;      /* number of data points */

/* open file position.txt for reading */
stream = fopen("position.txt", "r");
if(stream == NULL) {
    printf("Error: cannot open 'position.txt' for reading\n");
    exit(-1);
}

/* read the number of data points */
fscanf(stream, "%d", &n);
/* declare data for plotting */
double t[n], p[n];

/* read all data points */
for(i=0; i<n; i++) {
    fscanf(stream, "%lf%lf", &t[i], &p[i]);
}
fclose(stream);           /* close the file stream */
/* plot the data */
plot.title("Position Plot");
plot.label(PLOT_AXIS_X, "time (seconds)");
plot.label(PLOT_AXIS_Y, "position (meters)");
plot.data2DCurve(t, p, n);
plot.plotting();

```

Program 9.2: Read and plot data in the data file position.txt.

9.3. Plotting Data in Data Files for Graphical Display

read two numerical data, one for time and the other for position, in a line in the file `position.txt` into an element of array `t` and an element of array `p`. Before the data in arrays `t` and `p` are plotted, the opened file is closed by the function call

```
fclose(stream);
```

 Do Exercises 2 and 3 on page 174.

9.2.1 Using Functions `feof()`

The first integer number in the data file `position.txt` in Figure 9.1 gives the total number of data points. Program 9.2 uses this value to declare arrays and, in the conditional expression, to determine the number of data points to be read. Sometimes, a program may need to process a data file, where the number of data points is not known in advance. In this case, the function `feof()` can be used to determine whether there is still data to be read from an input file and continues to read from the file until the end-of-file indicator is reached. The function call

```
feof(stream)
```

returns a non-zero value when the *end-of-file indicator* (EOF) has previously been detected reading the named input stream. It returns 0 otherwise. In other words, the function call `feof(stream)` returns 0 until the end of the file is reached.

As an example, Program 9.3 reads the data for time and position in the data file `position1.txt` shown in Figure 9.3, and displays the data on the screen. The data in Figure 9.3 are the same as that in Figure 9.1, except without the first integer value in Figure 9.1. The statement

```
fscanf(stream, "%s", &line);
```

reads the first comment line in the file `position1.txt`. The code fragment

```
fscanf(stream, "%lf%lf", &t, &p);
/* print and read remaining data points */
while(!feof(stream)) {
    printf("%lf %lf\n", t, p);
    fscanf(stream, "%lf%lf", &t, &p);
}
```

reads the remaining data in the file and prints the data on the screen.

 Do Exercise 4 on page 174.

9.3 Plotting Data in Data Files for Graphical Display

Prerequisite: Understanding advanced variable types, program structure, arithmetic and relational operators, looping, user-defined functions, working with data files

Common Core Content Standards: L.6.6, RST.6-12.3, RST.6-12.4

CTE Model Curriculum Standards: Information Technology Pathway, D1.1, D1.3, D1.4, D2.1, D2.2, D2.3, D4.1

9.3. Plotting Data in Data Files for Graphical Display

```

/* File: posread.ch
   Read the positions from file position.txt and plot it */
#include <chplot.h>
string_t line;      /* line buffer */
FILE *stream;        /* a file stream */
double t, p;         /* time and positions */

/* open file position1.txt for reading */
stream = fopen("position1.txt", "r");
if(stream == NULL) {
    printf("Error: cannot open 'position1.txt' for reading\n");
    exit(-1);
}

/* read the first comment line */
fscanf(stream, "%s", &line);
printf("%s", line);
/* read the first data point */
fscanf(stream, "%lf%lf", &t, &p);
/* print and read remaining data points */
while(!feof(stream)) {
    printf("%lf %lf\n", t, p);
    fscanf(stream, "%lf%lf", &t, &p);
}
fclose(stream);           /* close the file stream */

```

Program 9.3: Read and display data in the data file position1.txt.

```

# The data set for time and position with 6 points
0.000000 55.000000
2.000000 23.000000
4.000000 7.000000
6.000000 7.000000
8.000000 23.000000
10.000000 55.000000

```

Figure 9.3: The contents of the data file position1.txt.

9.3. Plotting Data in Data Files for Graphical Display

```
/* File: posplotf.ch
   Plot data in file position1.txt */
#include <chplot.h>
CPlot plot;
string_t filename = "position1.txt",
         title    = "Position Plot",
         xlabel   = "time (seconds)",
         ylabel   = "position (meters)";

plot.title(title);
plot.label(PLOT_AXIS_X, xlabel);
plot.label(PLOT_AXIS_Y, ylabel);
plot.dataFile(filename);
plot.plotting();
```

Program 9.4: Plotting data in the data file position1.txt.

Objective: Write computer code to plot graphs by sending data files to the **CPlot** member functions.

9.3.1 Plotting a Curve Using the Member Function **dataFile()**

The member function **dataFile()** can be used to plot data in a data file in the form of

```
plot.dataFile(filename);
```

The argument of the string type specifies the data file. The format of the data file can be in a different format. The simple format is to have two columns of data. The data in the first column are for values in the x axis and the data in the second column are for y axis. A line starting with the symbol '#' is ignored. Therefore, comments starting with the symbol '#' can be added to a data file

As an example, assume that the data for time and position of a moving vehicle are saved in the data file position1.txt as shown in Figure 9.3. Program 9.4 using the member function **dataFile()** to plot the data in the data file position1.txt with the output shown in Figure 7.4.

 Do Exercise 5 on page 174.

9.3.2 Plotting Multiple Curves Using Different Data Files in a Single Plot

Using the member function **plot.dataFile()**, a program can plot a figure with multiple data sets in different data files. For example, Program 9.5 plots data in files position1.txt and position2.txt. The data file position2.txt is similar to the data file position1.txt, but with 21 points. It can be generated using Program 9.1 by changing the incremental step size from 2 to 0.5. The plot generated by Program 9.5 is shown in Figure 7.6 in Chapter 7.

 Do Exercises 6 and 7 on page 174.

9.4. Chapter Summary

```
/* File: posdataFile.ch
   Plot data in files position1.txt and position2.txt */
#include <chplot.h>
CPlot plot;
string_t filename = "position1.txt",
         title    = "Position Plot",
         xlabel   = "time (seconds)",
         ylabel   = "position (meters)";
int datanum = 0;

plot.title(title);
plot.label(PLOT_AXIS_X, xlabel);
plot.label(PLOT_AXIS_Y, ylabel);
plot.dataFile(filename);
plot.legend("6 points", datanum);
plot.dataFile("position2.txt");
datanum++;
plot.legend("21 points", datanum);
plot.plotting();
```

Program 9.5: Plotting data in the data files position1.txt and position2.txt.

9.4 Chapter Summary

9.4.1 Programming Tips

Good Programming Practice

1. Check the returned value from the function **fopen()**. For example,

```
stream = fopen("filename", "w");
if(stream == NULL) {
    printf("Error: cannot open file 'filename' for writing\n");
    return -1;
}
```

Common Programming Errors

1. Open a nonexistent file for reading.
2. Open a file for writing into a directory without write permission.

9.4.2 Terminology

General Concepts

input	output	stream
-------	--------	--------

C Reserved Words

fclose()	feof()	fprintf()
FILE	fopen()	
fscanf()		

9.5. Exercises

The Plotting Class CPlot

CPlot::dataFile()

9.5 Exercises

1. Write a program using a **for** loop to put the following numbers to a file named `record.dat`.
1 2 3 4 5 6 7 8 9 10
2. Write a program to read data in the file `record.dat` created in Exercise 1 and display them on the screen.
3. Write a program to save the following sequence of numbers in a file named `number.dat`. Then, read the data in this file and display the numbers on the screen.

1 3 5 7 9 11

4. The height for each student in a class has been measured and saved in the file `height.data`, with the data shown below.

5.4 5.5 5.6 5.7 5.5

Write a program `height.ch` to read the data in this file and calculate the average height for students in the class.

5. The data for time and corresponding position of the soccer ball described in Exercise 11 on page 163 are in the file `soccerball11.txt`. Write a program `soccerplot.ch` to plot the trajectory of the soccer ball based on the data in the file.
6. For the same soccer ball described in Exercise 11 on page 163, another set of data recorded in Table 8.4 in Exercise 14 is saved in the file `soccerball12.txt`. Write a program `soccerdataFile.ch` to display the trajectories of the soccer ball with data in both files `soccerball11.txt` and `soccerball12.txt`.
7. Modify the program `scatterplot2.ch` in Program 8.8 as a new program `scatterplot3.ch` to plot data in a data file using the member function `plot.dataFile()`. The file name will be entered by the user from the keyboard interactively.

CHAPTER 10

Quick Animation

10.1 Introduction

In Chapter 4, we learned how to draw objects including lines, rectangles, circles, etc. using member functions of the plotting class **CPlot**. In this chapter, we will learn how to animate these objects. A flip book is made up of several pictures that vary gradually from one page to the next. When you flip through the pages it gives the illusion of movement. Computer animation is very similar to this, the only difference is that the pictures are images on the computer and the computer displays one image after another at a fast pace to give the appearance of movement.

In the previous chapters, we learned to write computer programs with the file extension `.ch` in ChIDE. The program, written based on the Ch language syntax, is then processed by another program called **ch** through ChIDE. QuickAnimationTM is a product name for the program **qanimate** for quick animation. The program **qanimate** can be used to process the user written animation program based on the QuickAnimation syntax with the file extension `.qnm`. ChIDE can also be used to develop animation programs with a file extension `.qnm` with syntax highlighting. The animation program can then be processed by the program **qanimate** through ChIDE directly.

A sample animation in QuickAnimationTM is shown in Figure 10.1. There are five circles in Figure 10.1. The QuickAnimationTM can display one circle at a time to animate as if a circle is moving up. In this chapter, we will learn how to develop animation programs in QuickAnimationTM with ChIDE.

For detailed information about QuickAnimation, see **QuickAnimation User's Guide** in the PDF file `C:\Ch\docs\qanimate.pdf`. and the web site <http://www.softintegration.com/docs/ch/qanimate/>.

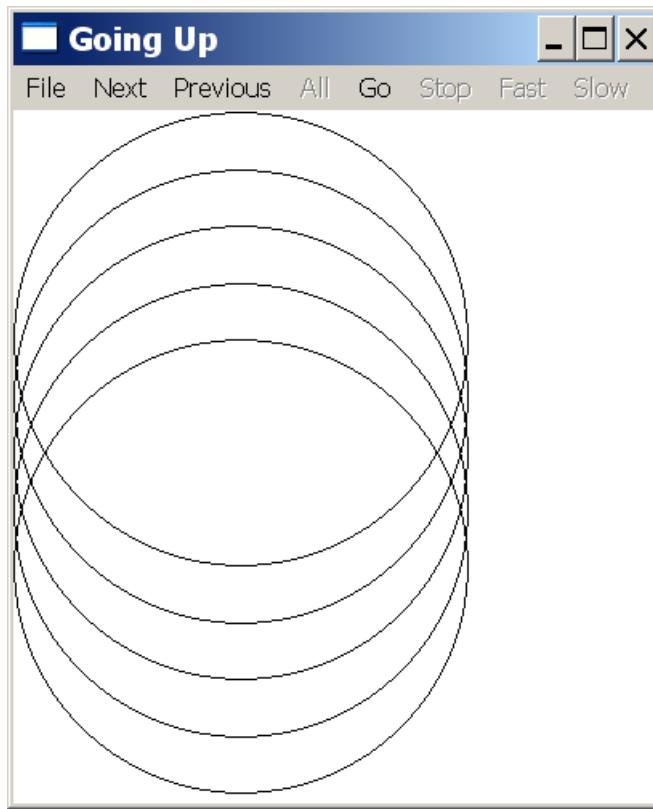


Figure 10.1: An animation of circles moving up in QuickAnimation™.

10.2 The First Animation Program

Let's get started with quick animation in ChIDE! We will write a simple program `circlesUp.qnm` with the file extension `.qnm` shown in Program 10.1.

```
# File: circlesUp.qnm
#
# This program starts with a circle with a radius of 4 units
# centered at (4,4) and moves it up five times 1 unit at a time.

title "Going Up"

animate reverse
circle 4 4 4
circle 4 5 4
circle 4 6 4
circle 4 7 4
circle 4 8 4
```

Program 10.1: Animating five circles moving up.

Like a Ch program, this animation program appears colored due to syntax highlighting in ChIDE. This program will create the animation shown in Figure 10.1.

We will explain each line in Program 10.1 in detail. Just like programs in Ch, comments are important to help people read and understand a program. All comments in a QuickAnimation program needs to start with the # character. It comments out a subsequent text till the end of a line. Lines in Program 10.1

```
# File: circlesUp.qnm
#
# This program starts with a circle with a radius of 4 units
# centered at (4, 4) and moves it up five times 1 unit at a time.
```

are comments for the program. They document that the file name of the animation program is `circleUp.qnm`. The purpose of the program is to animate a circle with a radius of 4 units. The circle is centered at the coordinate (4, 4) originally and moves up five times, 1 unit at a time.

The statement

```
title "Going Up"
```

adds the title `Going Up` to the animation as shown in Figure 10.1. The **title** is a keyword in QuickAnimation. The text in a string within a pair of double quotation mark following the keyword **title** is the title.

The **animate** is a keyword in QuickAnimation. All objects for animation are placed in the subsequent lines after the line

```
animate
```

with the keyword **animate**.

The **circle** is also a keyword in QuickAnimation for drawing a circle. The syntax for drawing a circle is as follows.

```
circle x y radius
```

It draws a circle at centered at (x, y) specified in the first and second arguments with a radius specified in the third (last) argument. Five statements below in Program 10.1

```
circle 4 4 4
circle 4 5 4
circle 4 6 4
circle 4 7 4
circle 4 8 4
```

draw five circles with a radius of 4 units, one at a time. The first circle is centered at (4, 4), the second one is at (4, 5), and the last one is at (4, 8). Therefore, a circle moves up five times, 1 unit at a time. The QuickAnimation program sets up the coordinate system automatically.

A QuickAnimation program with the file extension `.qnm` can be edited in ChIDE with syntax highlighting and line numbers, as shown in Figure 10.2. The animation for the program `circlesUp.qnm` can be created by clicking the command `Animate->qanimate` (`Animate a qnm file`) or the function key F10, as shown in Figure 10.2. The output from executing the program `circlesUp.qnm` is shown in Figure 10.1. By default, it displays all frames for the animation. In the next section, we will learn how to use the user interface for QuickAnimation.

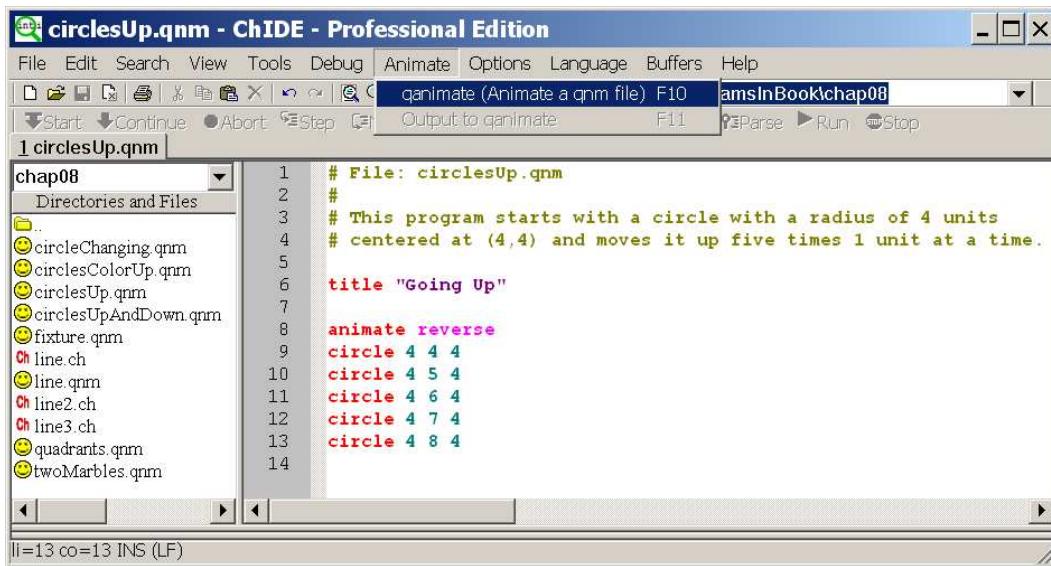


Figure 10.2: Running the QuickAnimation program `circlesUp.qnm` in ChIDE.

10.3 User Interface for QuickAnimation

When the QuickAnimation user interface is shown up, all frames in each snapshot will be displayed as shown in Figure 10.1 with five circles, one circle for each snapshot. The menu bar in the QuickAnimation user interface contains a series of menus which can be used to manipulate the animated objects. In Figure 10.1, the `File` menu allows the user to quit the program. The `All` button displays all frames at once. The `Fast` and `Slow` buttons change the speed of animation. The `Go` and `Stop` buttons start and stop the animation, respectively. The animation can move in either direction by pressing the `Next` button in one direction or the `Prev` button in the opposite direction.

The direction of animation for displaying frames can be changed. When the `Go` button is pressed, the animation will move forward if the user first pressed the `Next` button. On the other hand, if the user first pressed the `Prev` button and then for the `Go` button the animation will move backwards.

Do Exercise 1 on page 192.

10.4 Drawing Primitives

Primitives are objects that the user can draw. We have used the circle primitive in Program 10.1. There are many primitives in QuickAnimation. Table 10.1 lists some of the most commonly used primitives.

Table 10.1: The commonly used primitives in QuickAnimation™.

<p>Syntax:</p> <p style="color: red;">point x y</p> <p>Output:</p>	<p>Syntax:</p> <p style="color: red;">text x y “<i>string</i>”</p> <p>Output:</p> <p><i>string</i></p>
<p>Syntax:</p> <p style="color: red;">circle x y <i>radius</i></p> <p>Output:</p>	<p>Syntax:</p> <p style="color: red;">line x_1 y_1 x_2 y_2 [... x_n y_n]</p> <p>Output:</p>
<p>Syntax:</p> <p style="color: red;">polygon x_1 y_1 x_2 y_2 x_2 y_2 ... x_n</p> <p>Output:</p>	<p>Syntax:</p> <p style="color: red;">rectangle x y <i>width</i> <i>height</i> [angle <i>angle</i>]</p> <p>Output:</p>

Table 10.1 presents the syntax and output for point, text, circle, line, polygon, and rectangle. In QuickAnimation, **point**, **text**, **circle**, **line**, **polygon**, and **rectangle** are keywords for primitives. A point can be drawn with a coordinate (x, y) . A text in a string can be drawn at the position (x, y) for the first character of the string. As we have learned previously, a circle can be drawn by specifying its center point (x, y) and radius. Consider the syntax for drawing a line. One may specify a line by typing **line** followed by the x and y coordinates of the starting and ending points of the line. For example, the statement

```
line 0 0 2 3
```

draws a line from the origin (0, 0) to the point (2,3). Multiple lines may be linked together by adding more coordinate points after the keyword **line**. For example, the statement

```
line 0 0 2 3 6 7
```

will draw a line from the origin (0, 0) to the point (2,3), then to the point (6, 7). The syntax for a polygon is similar to that for a line. However, for a polygon, the last point will connect with the first point. A rectangle is specified with the position (x, y) for the lower left corner as well as the width and height as follows.

```
rectangle x y width height
```

A rectangle can be rotated about the lower left corner by an angle in degrees counter-clock wise using a statement below.

```
rectangle x y width height angle angle
```

The first **angle** is a reserved word in QuickAnimation. For example, the statement

```
rectangle 0 0 3 4 angle 90
```

will draw a rectangle with the lower left corner at the origin (0, 0). The rectangle has width of 3 and height 4, rotated by 90 degrees counter-clock wise.

10.5 Adding Fixtures

If you want to have primitives fixed without changing during the animation, they have to be placed after the keyword **fixture**.

Example In this example, we will use lines and text as fixtures.

Problem Statement:

Write an animation program `quadrants.qnm` that draws a fixed coordinate plane from -5 to 5. Then animate the labels of each quadrant by showing each label one at a time.

```
# File: quadrants.qnm
#
# This program draws a fixed coordinate plane
# from -5 to 5. Then it animates the labels of
# each quadrant by showing them one at a time.

title "Four Quadrants"

fixture
line -5 0 5 0
line 0 -5 0 5
text 5 0 "x"
text 0.1 5 "y"

animate
text 2 2.5 "Quadrant I"
text -3.5 2.5 "Quadrant II"
text -3.5 -2.5 "Quadrant III"
```

```
text 2 -2.5 "Quadrant IV"
```

Program 10.2: Drawing and labeling the four quadrants.

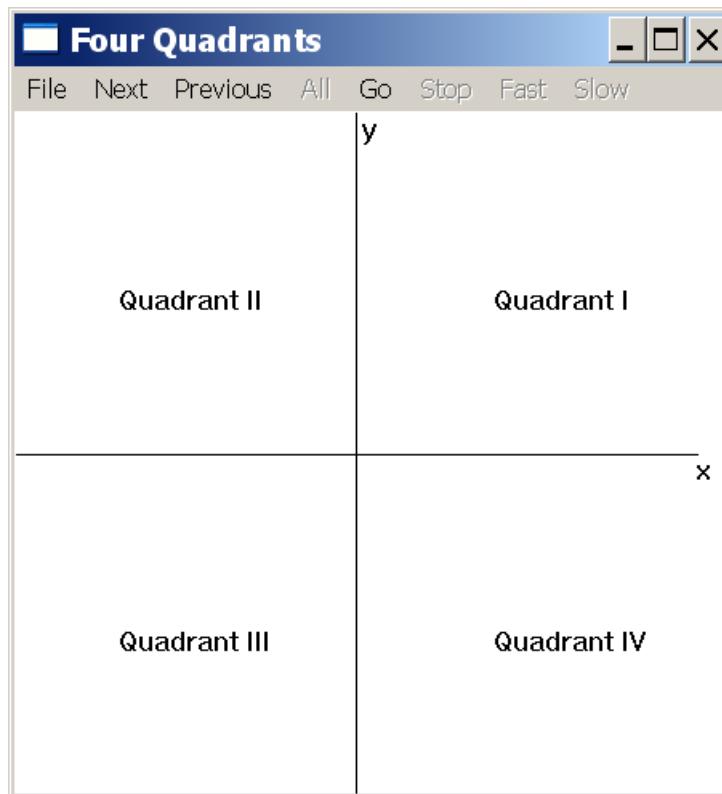


Figure 10.3: The output generated by Program 10.2.

The output from Program 10.2 with a user interface of QuickAnimation is shown in Figure 10.3. In Program 10.2, statements

```
fixture
line -5 0 5 0
line 0 -5 0 5
```

draws a line from $(-5, 0)$ to $(5, 0)$ for the x-coordinate and a line from $(0, -5)$ to $(0, 5)$ for the y-coordinate as fixtures. Statements

```
text 5 0 "x"
text 0.1 5 "y"
```

add the label x at $(5, 0)$ and label y at $(0.1, 5)$ as fixtures. Statements

```
animate
text 2 2.5 "Quadrant I"
text -3.5 2.5 "Quadrant II"
text -3.5 -2.5 "Quadrant III"
text 2 -2.5 "Quadrant IV"
```

add four quadrants, one frame for each quadrant for animation.

 Do Exercise 2 on page 192.

10.6 Color and Filling

To change the color for the *outline* of a primitive, you add the code below at the end of its line to change the color of the pen:

pen color

where **color** is a color name such as **red** and **green**. Similarly, to change the color *inside* of a primitive, you add the code below at the end of its line to change the filling color:

fill color

Both reserved word **pen** and **fill** can be added at the same time. For example, the statement

```
circle 3 3 4 pen red fill blue
```

will draw a circle with the radius of 4 centered at (3, 3). The outline of the circle is red and the circle is filled with the blue color.

Example In this example, we will illustrate the use of color.

Problem Statement:

Modify the program **circlesUp.qnm** so that each circle has a different outline and fill color. Call the new program **circlesColorUp.qnm**.

```
# File: circlesColorUp.qnm
#
# This program starts a circle with radius 4 centered at (4,4)
# and has it move up 5 times one unit at a time. Each
# time the fill and outline of the color of the circle changes.

title "Going Up and Changing"

animate
circle 4 4 4 pen yellow fill blue
circle 4 5 4 pen green fill gray
circle 4 6 4 pen black fill green
circle 4 7 4 pen red fill purple
circle 4 8 4 pen cyan fill pink
```

Program 10.3: Animating five circles moving up with a fill color different from the pen color.

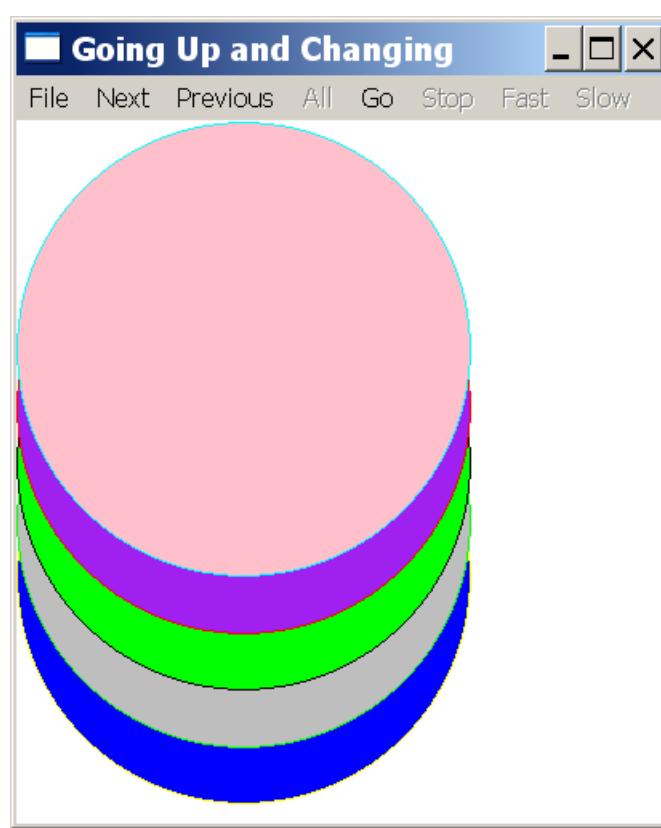


Figure 10.4: The output generated by Program 10.3.

The output from Program 10.3 with a user interface of QuickAnimation is shown in Figure 10.4.

 Do Exercise 3 on page 193.

10.7 Changing How the Animation Restarts

By default, when an animation is finished, it starts again from the beginning. To change this default behavior, you need to add the reserved word **reverse** after the keyword **animate** as follows.

```
animate reverse
```

Once the reserved word **reverse** is added, when the animation is finished, it starts the animation from the last frame and moves in the reverse until the first frame is reached. Then the animation repeats from the beginning. The animation will continue repeating until the **Stop** button is pressed or the program is exited.

Example In this example, we will illustrate the use of reverse animation.

Problem Statement:

Modify the program `circlesUp.qnm` so that once the last circle reaches the top, the circles start moving back down. Call the new program `circlesUpAndDown.qnm`.

```
# File: circlesUpAndDown.qnm
#
# This program starts with a circle with a radius of 4 units centered at (4, 4)
# and moves it up 4 times, 1 unit at a time. Once the last circle reaches the top,
# the circles starts moving back down.

title "Going Up and Down"

animate reverse
circle 4 4 4
circle 4 5 4
circle 4 6 4
circle 4 7 4
circle 4 8 4
```

Program 10.4: Animating five circles moving up and down.

 Do Exercise 4 on page 193.

10.8 Changing Line Width and Line Style

Changing the width of a line is very similar to changing the color of the line. To change the width of a line, you use the reserved word **linewidth** followed with a pixel width in a whole number as follows:

linewidth pixelwidth

By default, lines are solid. The reserved word **linestyle** can be used to change the default solid line to dashed or dotted line. To have a dashed line, use

linestyle dashed

to modify a primitive. For example, the statement

```
circle 3 3 4 linewidth 6 pen red
```

will draw a circle with the radius of 4 centered at (3, 3). The line width of the circle is 6 pixels in red. To have a dotted line, use

linestyle dotted

to modify a primitive. For example, the statement

```
circle 3 3 4 linestyle dotted pen red
```

will draw a circle in a dotted line in red.

Example In this example, we will illustrate the use of line width and line style.

Problem Statement:

Write an animation program `circleChanging.qnm` that starts with one solid circle of radius 5. Then the line thins and it changes to being dashed. Afterwards the line becomes

dotted. Once all of the snapshots finish the first time it needs to start from the end and move in the reverse.

```
# File: circleChanging.qnm
#
# This program starts with one solid circle of radius 5. Then the
# line thins and it changes to being dashed. Afterwards the line
# becomes dotted. Once all of the snap shots finish the first time
# it needs to start from the end and move in the reverse.

title "A Changing Circle"

animate reverse
circle 5 5 5 linewidth 30 pen red
circle 5 5 5 linewidth 25 pen red
circle 5 5 5 linewidth 20 pen red
circle 5 5 5 linewidth 15 pen red
circle 5 5 5 linewidth 10 pen red
circle 5 5 5 linewidth 5 pen red
circle 5 5 5 linewidth 1 pen red
circle 5 5 5 linestyle dashed pen red
circle 5 5 5 linestyle dotted pen red
```

Program 10.5: Animating a circle with its outline changing.

 Do Exercise 5 on page 193.

10.9 A Snapshot with Multiple Primitives

More advanced animations will need several primitives to animate at the same time. If you want to have two or more primitives to animate at the same snapshot , they can be placed in the same line. Each primitive will start with a keyword. For example, the statement

```
circle -7 1 1 fill yellow circle 1 1 1 fill green
```

will draw two circles with the radius of 1. Each circle is specified by the keyword **circle**. The first circle is centered at $(-7, 1)$ and filled with the yellow color. The second circle is centered at $(1, 1)$ and filled with the green color.

If a line is too long to read conveniently, you may break the line with multiple primitives for a single snapshot into multiple lines. **Each line for the same snapshot needs to end with a backslash (\) immediately followed by a return character, except the last line.** For example, the statements below

```
circle -7 1 1 fill yellow circle 1 1 1 fill green \
circle 5 1 1 fill red   circle 10 1 1 fill gray \
rectangle 0 0 3 4 fill purple
```

will draw four circles and one rectangle at a single snapshot.

Example In this example, we will have two primitives at the same snapshot.

Problem Statement:

Write an animation program `twoMarbles.qnm` with two marbles. The first marble

bumps into the second one. Then the second marble falls off the edge.

```
# File Name: twoMarbles.qnm
#
# This program has one marble bump into another marble. Then
# the second marble falls off the edge.

title "Two Marbles"

fixture
line -7 0 5 0 linewidth 7 pen gray

animate
# The first marble is rolling
circle -7 1 1 fill yellow circle 1 1 1 fill green
circle -6 1 1 fill yellow circle 1 1 1 fill green
circle -5 1 1 fill yellow circle 1 1 1 fill green
circle -4 1 1 fill yellow circle 1 1 1 fill green
circle -3 1 1 fill yellow circle 1 1 1 fill green
circle -2 1 1 fill yellow circle 1 1 1 fill green
circle -1 1 1 fill yellow circle 1 1 1 fill green

# The second marble is rolling
circle -1 1 1 fill yellow circle 1 1 1 fill green
circle -1 1 1 fill yellow circle 2 1 1 fill green
circle -1 1 1 fill yellow circle 3 1 1 fill green
circle -1 1 1 fill yellow circle 4 1 1 fill green
circle -1 1 1 fill yellow circle 5 1 1 fill green

# The second marble is falling
circle -1 1 1 fill yellow circle 6 1 1 fill green
circle -1 1 1 fill yellow circle 6.2 0 1 fill green
circle -1 1 1 fill yellow circle 6.4 -1 1 fill green
circle -1 1 1 fill yellow circle 6.6 -2 1 fill green
circle -1 1 1 fill yellow circle 6.6 -3 1 fill green
```

Program 10.6: Animating one marble bumping another off an edge.

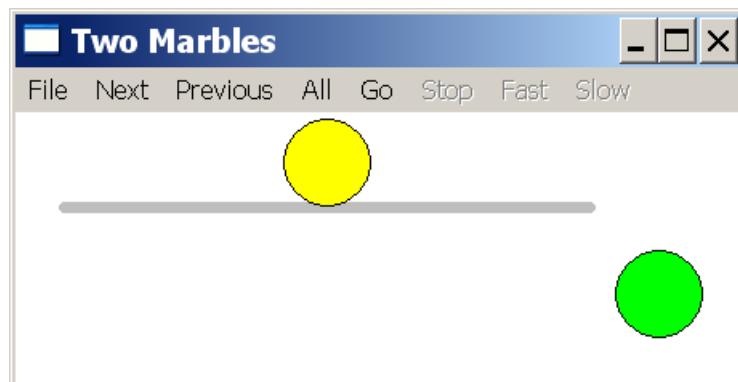


Figure 10.5: The output generated by Program 10.6.

The statements in Program 10.6

```
fixture
line -7 0 5 0 linewidth 7 pen gray
```

will draw a horizontal line from $(-7, 0)$ to $(5, 0)$ with the line width of 7 pixels in gray color. This fixture acts as a supporting surface for two marbles.

The animation in Program 10.6 has three parts. In the first part, the first marble rolls from the left toward the right till it hits the second marble in stationary. In the second part, the first marble is stationary and the second marble will move toward the right. In the third part, the first marble is still stationary and the second marble will move toward the south.

The output from Program 10.6 with a user interface of QuickAnimation is shown in Figure 10.5.

 Do Exercise 6 on page 193.

10.10 Writing Ch Programs for Quick Animation

A Ch program with the file extension .ch can be written to generate an animation program in the QuickAnimation syntax. Functions and loops in Ch can be used to conveniently create complicated animations for various applications. In this section, we will learn how to write Ch programs for quick animation.

Program 10.7 animates the points for the linear function $y = \frac{3}{2}x - 2$. The statements

```
fixture
line -8 0 8 0 linewidth 2 pen gray
line 0 -8 0 8 linewidth 2 pen gray
text 8 -0.2 "x"
text 0.2 8 "y"
```

draw the x and y coordinates as fixtures. The remaining part of the program animates points from the function $y = \frac{3}{2}x - 2$. For example, the point $(-4.00, -8.00)$ is a point (x, y) on the line representing the function.

```
# File: line.qnm
# This program animates the points for the function y=(3/2)x-2.
#
title "The points of y=(3/2)x-2"

fixture
line -8 0 8 0 linewidth 2 pen gray
line 0 -8 0 8 linewidth 2 pen gray
text 8 -0.2 "x"
text 0.2 8 "y"

animate
point -4.00 -8.00
point -2.00 -5.00
point 1.00 -0.50
point 3.00 2.50
point 5.00 5.50
point 7.00 8.50
```

Program 10.7: Animating points for the function $y = \frac{3}{2}x - 2$.

The output from Program 10.7 with a user interface of QuickAnimation is shown in Figure 10.6.

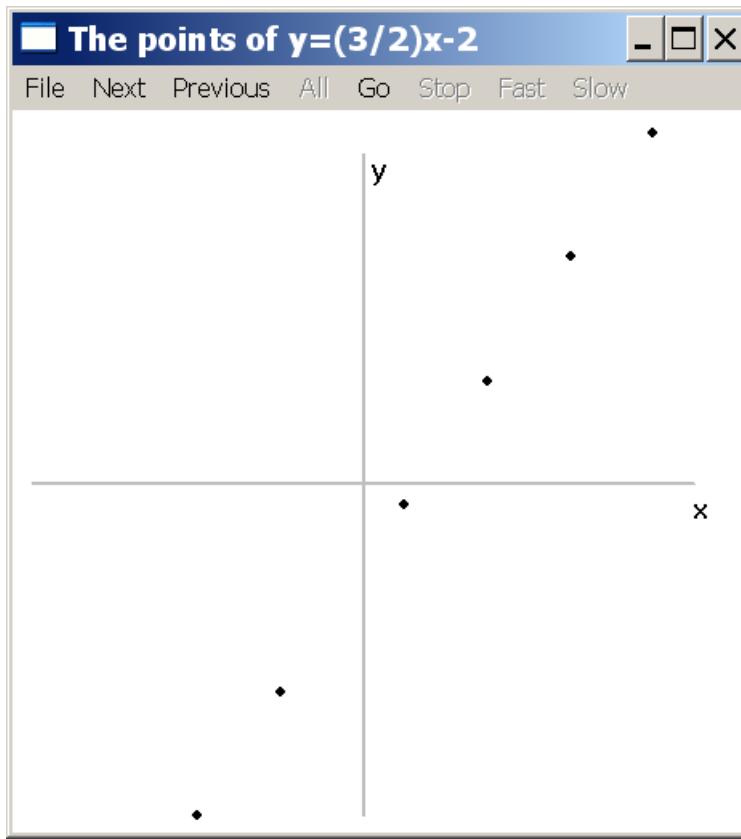


Figure 10.6: The output with moving points alone a line generated by Program 10.7.

The animation program shown in Program 10.7 can be generated by a Ch program listed in Program 10.8. Notice that to produce a double quotation mark in the output, you need to add backslash (\) before it. The animation statement followed with an empty line

```
title "The points of y=(3/2)x-2"
```

is generated by the following Ch program statement with two return characters "\n\n".

```
printf("title \"The points of y=(3/2)x-2\"\n\n");

/* File: line.ch
   This program generates a QuickAnimation output
   using points of the function y=(3/2)x-2 for animation */

printf("# File: line.qnm\n");
printf("# This program animates the points for the function y=(3/2)x-2.\n");
printf("#\n");
printf("title \"The points of y=(3/2)x-2\"\n\n");

printf("fixture\n");
printf("line -8 0 8 0 linewidth 2 pen gray\n");
printf("line 0 -8 0 8 linewidth 2 pen gray\n");
printf("text 8 -0.2 \"x\"\n");
printf("text 0.2 8 \"y\"\n\n");
```

```

printf("animate\n");
printf("point -4.00 -8.00\n");
printf("point -2.00 -5.00\n");
printf("point 1.00 -0.50\n");
printf("point 3.00 2.50\n");
printf("point 5.00 5.50\n");
printf("point 7.00 8.50\n");

```

Program 10.8: Generating a QuickAnimation output using points of the function $y = \frac{3}{2}x - 2$.

When Program 10.8 is executed by clicking the command **Run** on the debug bar in ChIDE, the output as shown in Program 10.7 will be displayed in the input/output pane. We can copy and save this output in a new animation program with the file extension .qnm in ChIDE. Then, run it from ChIDE. However, the standard output from a Ch program can be sent to the QuickAnimation program **qanimate** directly in ChIDE by clicking the command **Animate->Output to qanimate** on the menu bar or the function key F11, as shown in Figure 10.7 for running Program 10.8.

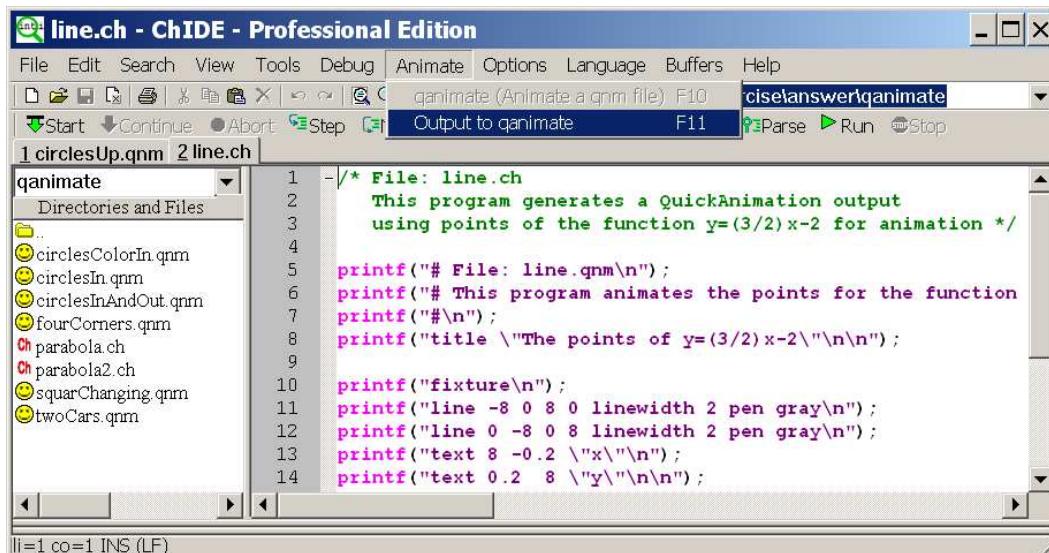


Figure 10.7: Running the Ch program `line.ch` for quick animation in ChIDE.

Application: Writing a Ch Program for Quick Animation of a Line

Problem Statement:

Write a Ch program `line2.ch` that generates an animation that draws the x and y axis from -8 to 8. Then it animates the points of the function $y = \frac{3}{2}x - 2$ from $x = -4$ to $x = 7$ with an increment of 0.5.

```

/* File: line2.ch
This program generates a QuickAnimation output
with points of the function y=(3/2)x-2 for animation */

```

```

printf("# File: line.qnm\n");
printf("# This program animates the points for the function y=(3/2)x-2.\n");
printf("#\n");
printf("title \"The points of y=(3/2)x-2\"\n\n");

printf("fixture\n");
printf("line -8 0 8 0 linewidth 2 pen gray\n");
printf("line 0 -8 0 8 linewidth 2 pen gray\n");
printf("text 8 -0.2 \"x\"\n");
printf("text 0.2 8 \"y\"\n\n");

printf("animate\n");
double x;
x=-4;
while(x<=7) {
    printf("point %.2lf %.2lf\n", x, 3.0/2.0*x-2);
    x=x+0.5;
}

```

Program 10.9: Generating a QuickAnimation output using a **while** loop to create points of the function $y = \frac{3}{2}x - 2$.

Program 10.9 is the same as Program 10.8, except that it generates points for x from -4 to 7 with an increment step of 0.5 by using a **while** loop below.

```

double x;
x=-4;
while(x<=7) {
    printf("point %.2lf %.2lf\n", x, 3.0/2.0*x-2);
    x=x+0.5;
}

```

Alternatively, we can define a Ch function below

```

double func(double x){
    return 3.0/2.0*x - 2.0;
}

```

for the math function $y = \frac{3}{2}x - 2$. The function `func()` can then be called in a **for** loop below.

```

for(x=-4; x<=7; x=x+0.5){
    printf("point %.2lf %.2lf\n", x, func(x));
}

```

The program `line3.ch` using the above code is available in the distribution along with the program `line2.ch`.

The output from Program 10.9 by running the command `Animate->Output to qanimate` on the menu bar in ChIDE is shown in Figure 10.8 with a user interface of QuickAnimation. Comparing with Figure 10.6, Figure 10.8 contains more points for the function.

The combination of a Ch program with QuickAnimation is very powerful. You may explore various applications for different projects.

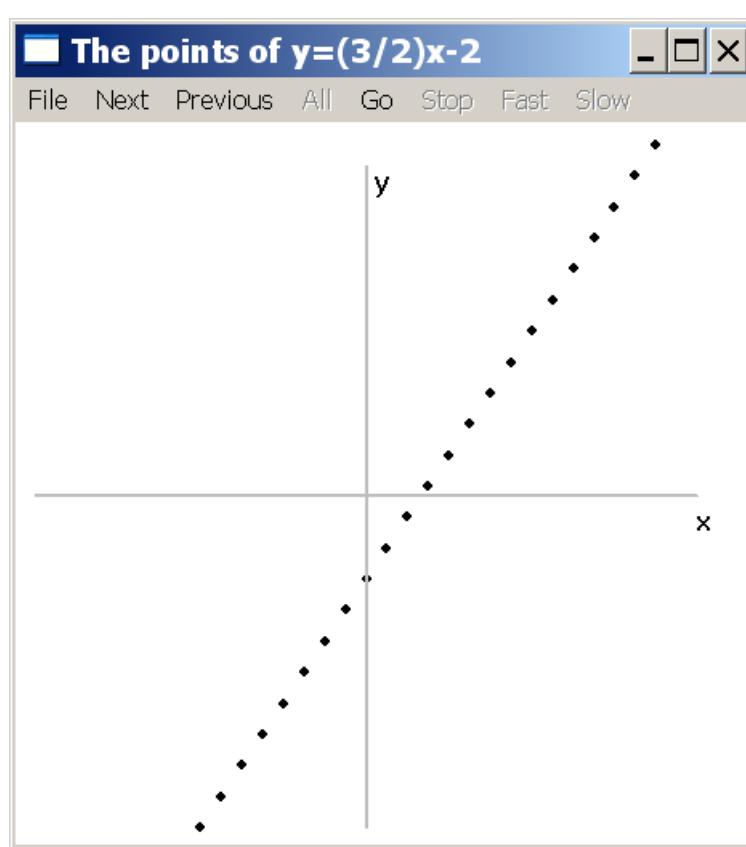


Figure 10.8: The output with moving points alone a line generated by Program 10.9.

 Do Exercise 7 on page 194.

10.11 Chapter Summary

10.11.1 Programming Tips

Good Programming Practice

1. Create an output with double quotation marks using a backslash (\) before it For example,

```
printf("title \"My animation title\"\n");
```

will output

```
title "My animation title"
```

10.11.2 Terminology

General Concepts

QuickAnimation animation frame primitive qanimate snapshot

QuickAnimation Keywords

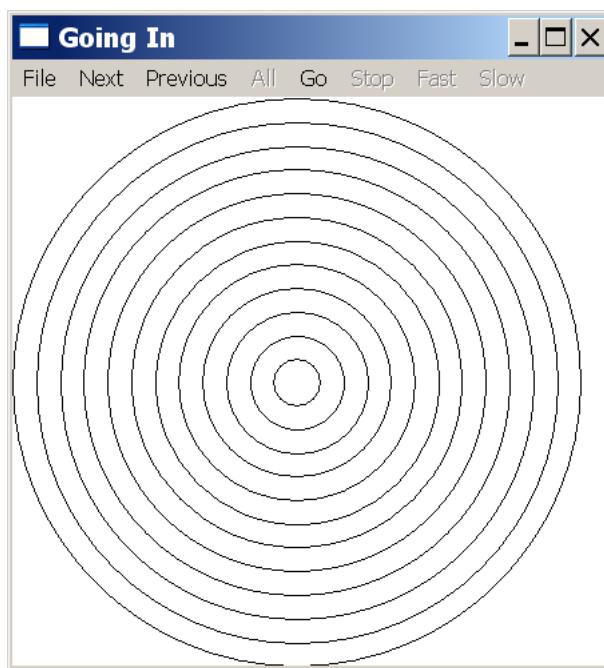
animate circle fixture line point polygon rectangle text title

QuickAnimation Reserved Words

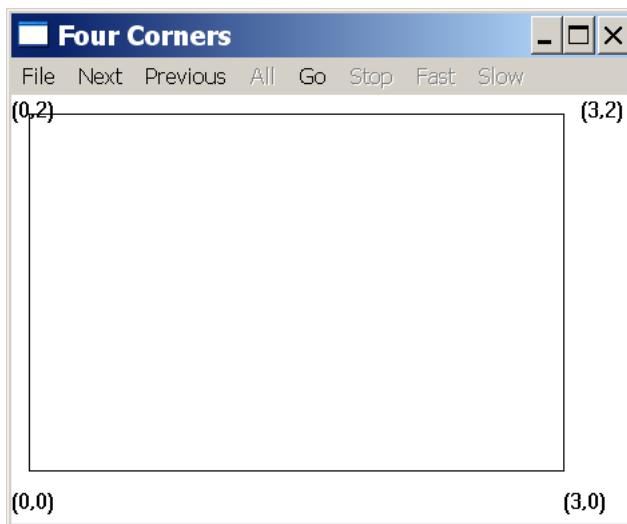
angle dashed dotted fill linestyle linewidth pen reverse

10.12 Exercises

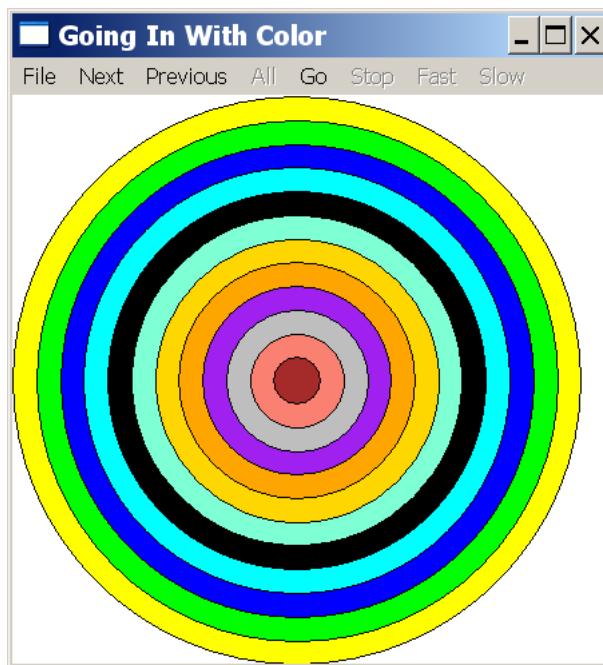
1. Write an animation program `circlesIn.qnm` which starts with a circle with a radius of 6 units centered at (6,6) and have it shrink by 0.5 units 12 times. *Note: Your code will draw 12 circles.*



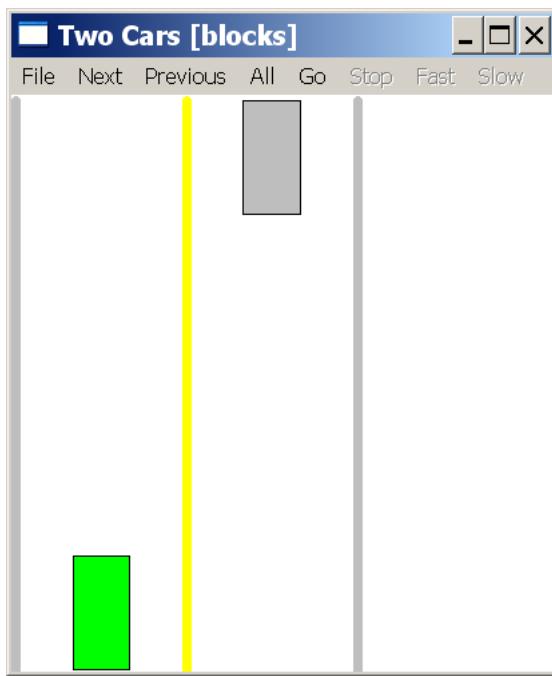
2. Write an animation program `fourCorners.qnm` which draws a fixed rectangle with its lower left corner at (0,0), with a width of 3 units and height of 2 units. Then have it animate the coordinates (x,y) of each of the rectangle's vertices by showing the coordinates one at a time.



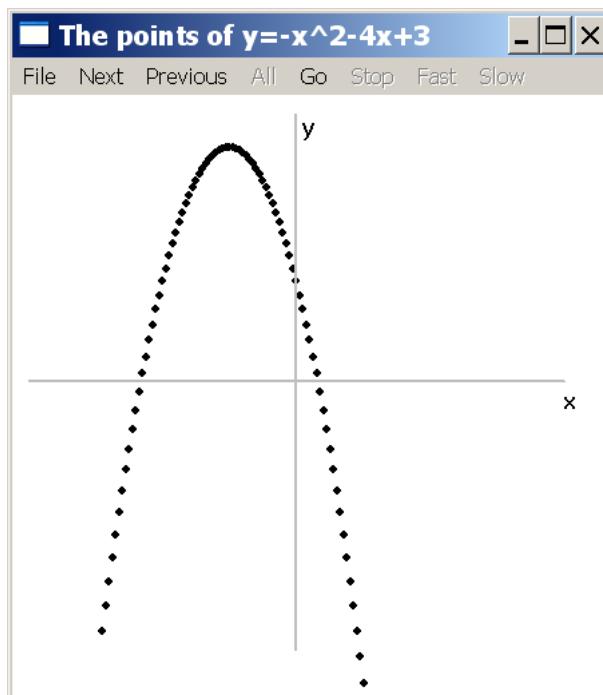
3. Modify the animation `circlesIn.qnm` so that each circle has a different outline and fill color. Call the new program `circlesColorIn.qnm`.



4. Modify the animation `circlesIn.qnm` so that once the last circle reaches the inside the circles start off going outwards (in the reverse direction). Call the new program `circlesInAndOut.qnm`.
5. Write an animation program `squaresChanging.qnm` that starts with one solid 4 by 4 square. Have the line get thinner then become dashed, and then lastly it needs to become dotted. After all of the snap shots finish the first time, the outline of the square needs to change in the reverse order (dotted to dashed, then thicker in width).
6. Write an animation program `twoCars.qnm` that starts with two cars [two rectangles]. The first car starts from the bottom and moves toward north 9 units. After the first car reaches the top, the second car starts at the top and moves toward south 9 units.



7. Write a Ch program `parabola.ch` that generates an animation that draws the x and y axis from -8 to 8. Then it animates the points of the function $y = -x^2 + 4x + 3$ from $x = -5.8$ to $x = 2$ with an increment of 0.1.



APPENDIX A

Using Function Files in Ch

You may develop a library of functions for an application. In this case, you may want to place each function in a function file. A **function file** in Ch is a file that contains only one function definition. The name of a function file ends in .chf, such as addition.chf. The names of the function file and function definition inside the function file must be the same. The functions defined using function files are treated as if they were system built-in functions in Ch. For example, the function **quadratic()** described in section 7.6.1 is implemented using a function file quadratic.chf with the contents listed in Program 7.11. The file quadratic.chf is located in the folder C:/Ch/lib/libch/numeric in Windows and /usr/local/ch/lib/libch/numeric in other platforms by default. The function **vertex()** described in Exercise 16 in Chapter 7 is implemented similarly.

We will use the function **addition()** in Program 7.1 as an example. If a file named addition.chf contains the code shown in Program A.1, the function **addition()** will be treated as a system built-in function, which can be called to perform the addition for its two arguments.

A function is searched based on the search paths in the system variable **_fpath** for function files. Each path is delimited by a semicolon. Assume that the function file addition.chf is located at C:/Documents and Settings/Administrator/learnch/addition.chf, the directory C:/Documents and Settings/Administrator/learnch should be added to the function search path in the start-up file **.chrc** in Unix or **_fpath** in Windows in the user's home directory with the following statement.

```
_fpath=stradd(_fpath, "C:/Documents and Settings/Administrator/learnch;");
```

You can use the command Options->Open Ch Local Startup File in ChIDE to open the start-up file to modify **_fpath**.

The function **addition()** then can be used either interactively in command mode as shown below,

```
> int sum;
> sum = addition(2, 3)
5
```

or inside programs. In Program A.2, the function **addition()** in the function file **addition.chf** is called. The output of Program A.2 is the same as that from Program 7.1.

If the search paths for function files have not been properly setup, an error message such as

```
ERROR: function 'addition()' not defined
```

will be displayed when the function **addition()** is called.

```
/* File: addition.chf
   A function file with file extension .chf */
int addition(int a, int b) {
    int c;
    c = a + b;
    return c;
}
```

Program A.1: The function file for the function `addition()` used by the program `additionf.ch`.

```
/* File: additionf.ch
   Use addition() in the function file addition.chf to add two integers */

int sum;      /* declare variable sum */

/* call function addition() to add 3 and 4, the return
   value from function is assigned to the variable sum */
sum = addition(3, 4);
printf("sum = %d\n", sum);
```

Program A.2: Calculating the sum using the function file `addition.chf` for addition.

APPENDIX B

Quick References to Ch

This appendix summarizes Ch features used in this book.

B.1 Reserved Keywords

array break double else for if int return void while

B.2 Reserved Names

cos CPlot FILE fclose feof fopen fprintf fscanf
MPI NULL pow printf randdouble randint remvar scanf
showvar sin sqrt tan

B.3 Punctuators

+ - * / () . \ " # &
{ } % == != < <= > >= && || ,

B.4 Comments

```
/* This is a comment */  
int i; // this is also a comment
```

B.5 Preprocessing Directives

The preprocessing directive: **#define** and **#include**

B.6. Header Files

```
#define N 10
#include <chplot.h>
```

B.6 Header Files

`#include <chplot.h>` for the plotting class **CPlot**.

B.7 Data Types

Integer type: **int**

Floating point type: **double**

String type: **string_t**

Generic type: **void**

B.8 Declaration of Variables

```
int i, n=10;                      // variables for integers
double x, y=1.2;                  // variables for decimals
string_t s1, s2="abc123";         // variables for strings
```

B.9 Declaration of Arrays

```
array double a[32], b[2]={1,2};    // variables for arrays
a[0] = a[31]; // accessing 1st and last elements of an array
```

B.10 Declaration of Functions (Call by Value)

```
/* define a function func(x) for y=2x-3 */
double func(double x) {
    double y;

    y = 2*x - 3;
    return y;
}
double x=10, y;
y = func(x);
```

B.11 Declaration of Functions (Call by Reference)

```
/* define a function func2(x, y) for y=2x-3 */
void func2(double x, double &y) { /* y is a reference type */
```

B.12. Define Macros

```

y = 2*x - 3;
return y;
}
double x=10, y;
func2(x, y);

```

B.12 Define Macros

```
#define N 10
```

B.13 Escape Characters and Special characters

Escape characters "\a" for an audible beep or visible alert, "\n" for a newline character, "\\\" for a backslash, and "\\\"" for a double quote character ". Print the special character "%%" for the percent symbol %. For example,

```

printf("Error!\a");                                // make an alert
printf("Hello, World\n");                          // a newline character
printf("This is the C:\\ drive\n");                // print \
printf("We sell Yogurt with 10%% discount\n"); // with 10% discount

```

B.14 Operators**B.14.1 Arithmetic Operators**

Description	Operator in math	Operator in Ch	Operation
addition	+	+	$x + y$
subtraction	-	-	$x - y$
multiplication	\times	*	$x * y$
multiplication	.	*	$x * y$
division	\div	/	x / y

Unless the result of a division operation is a whole number, to get the correct numerical result, one of the numbers must be inputted as a decimal number. For example, the math expression $\frac{2(3+4)}{5-6}$ can be inputted as `2.0 * (3+4) / (5-6)`.

B.14.2 Modulus Operator

```
odd = n % 2;      // odd is 1 if n is an odd number
```

B.14.3 Relational Operators

```
<    <=    ==    >=    >    !=
```

B.14.4 Logical Operators

```
&&    ||
```

```
++      --
i++;
```

B.15 The **if** Selection Statements

```
if(x<0)  {
    y = 2*x;
}
else if(1 <= x && x <= 2)  {
    y = 3*x;
}
else {
    y = 4*x;
}
```

B.16 The **while** and **for** Loops

<pre><code>int i, sum; /* the while-loop */ i=0; while(i < n) { sum = sum+i; i++; }</code></pre>	<pre><code>int i, sum; /* the for-loop */ for(i=0; i < n; i++) { sum = sum+i; }</code></pre>
---	---

B.17 Input Function **scanf()** and Output Function **printf()**

```
printf("i= %d, x = %lf\n", i, x); // print integer i and decimal x
printf("c= %c, s = %s\n", c, s); // print character c and string s
printf("%.2lf\n", x);           // print two digits after the decimal point
printf("%E\n", x);             // print x in scientific notation
scanf("%d", &i);              // get the user input for i
scanf("%d%lf", &i, &x);        // get the user input for i and x
scanf("%c", &c);              // get the user input for c
scanf("%s", &s);              // get the user input for s
```

B.18 Input to and Output from Files

```
int n;
string_t line;
FILE *stream1, *stream2;
stream1 = fopen("filename1", "w"); // open filename1 for writing
```

B.19. Math Functions

```

stream2 = fopen("filename2", "r");           // open filename2 for reading
fprintf(stream1, "%d", n);                  // write into "filename1"
fscanf(stream2, "%d", &n);                  // read from "filename2"
fscanf(stream2, "%s", &line);              // read a line from "filename2"
while(!feof(stream2)) {                     // read until end-of-file
    fscanf(stream2, "%d", &n);              // read from "filename2"
}
fclose(stream1);                           // close file stream1
fclose(stream2);                           // close file stream2

```

B.19 Math Functions

The square root function **sqrt**(x) is for \sqrt{x} . The exponential function **pow**(x, y) is for x^y . Trigonometric functions **sin()**, **cos()**, **tan()**, etc. Quadratic functions **quadratic()** and **vertex()**.

```

y = sqrt(x);
y = pow(x, 3);
y = sin(x);
y = cos(x);
y = tan(x);
quadratic(a, b, c, x1, x2);
vertex(a, b, c, h, k);

```

B.20 Random Number Generating Functions

```

n = randint(a, b);
x = randdouble(a, b);

```

B.21 Commands in a Ch Command Window

```

> remvar i           // remove variable i
> showvar            // display all variables and their values

```

B.22 Member Functions of the Plotting Class CPlot

This document uses several member functions of the plotting class **CPlot** to create and manipulate plots. Detailed information for member functions of the class **CPlot** can be found in the section for the header file **chplot.h** in **Ch Reference Guide**, which is available in a PDF file at C:\Ch\docs\chref.pdf. The usages of the member functions in this document are summarized in this appendix.

Math Symbols

The Ch plotting uses the enhanced text for strings such as title, labels, and legends. Special symbols for the enhanced text can be found in *Ch Reference Guide*. The strings "<=" and ">" represent \leq and \geq , respectively. To print a superscript on a plot, the symbol \wedge is used, such as x^2 for x^2 . To print a subscript on a plot, the symbol $_$ is used, such as x_2 for x_2 . The string "**M_PI**" is for π . The string "{ /Symbol @{\\"140}\\"326}x" is used to print a square root function sign \sqrt{x} .

B.22. Member Functions of the Plotting Class **CPlot****plot.arrow(x_head, y_head, x_tail, y_tail)**

adds an arrow to a plot. The arrow points from (x_tail, y_tail) to (x_head, y_head) . For example,

```
plot.arrow(x1, y1, x2, y2);
```

This member function can be used to draw arrows in x and y axes.

plot.axisRange(axis, minimum, maximum)

sets the minimum and maximum value for an axis. The first argument `axis` specifies which axis. The commonly used macros for the argument `axis` are `PLOT_AXIS_X` and `PLOT_AXIS_Y` for x-axis and y-axis, respectively. The second argument `minimum` is for the minimum value of the axis. The third argument `maximum` is for the maximum value of the axis. For example,

```
plot.axisRange(PLOT_AXIS_X, -10, 10);
plot.axisRange(PLOT_AXIS_Y, 10, 10);
```

plot.circle(x, y, radius)

draws a circle centered at the point (x, y) with the radius `r`. For example,

```
plot.circle(0, 0, 3);
```

plot.data2DCurve(x, y, n)

plots data in arrays `x` and `y` with the `n` number of points. For example,

```
plot.data2DCurve(x, y, n);
```

plot.dataFile(filename)

plots data in the data file `filename`. For example,

```
plot.dataFile("position.txt");
```

plot.enhanceText()

sets a plot to use the enhanced text for strings such as title, labels, and legends. Special symbols for the enhanced text can be found in *Ch Reference Guide*, available in a PDF file at `C:\Ch\docs\chref.pdf`. For example,

```
plot.enhanceText();
```

The strings `"/Symbol \u243"` and `"/Symbol \u263"` represent \leq and \geq , respectively. The string `"{/Symbol @{\u140}\u326}x"` is used to print a square root function sign \sqrt{x} . To print a superscript on a plot, the symbol `^` is used, such as `x^2` for x^2 .

plot.expr(x0, xf, num, expx)

plots a function defined as an expression `expx` in terms of the variable `x` in the range $[x_0, xf]$ with the number of points specified by the argument `num`. For example,

```
plot.expr(-10, 10, 500, "2*x+1");
```

plot.func2D(x0, xf, num, func)

plots a function defined as `func()` in the range $[x_0, xf]$ with the number of points specified by the argument `num`. For example,

```
plot.func2D(-10, 10, 500, func);
```

plot.grid(PLOT_ON)

adds grid lines to the plot. For example,

```
plot.grid(PLOT_ON);
```

B.22. Member Functions of the Plotting Class **CPlot****plot.grid(PLOT_ON, "front")**

adds grid lines to the plot. The second argument makes the grid line in a filled area visible. For example,

```
plot.grid(PLOT_ON, "front");
```

plot.label(axis, "string")

adds a label to an axis. For example,

```
plot.label(PLOT_AXIS_X, "x");
plot.label(PLOT_AXIS_Y, "y=2x+5");
```

plot.legend("legend", num)

adds a legend to the plot. The first argument is a string for the legend. The second argument is the number of the data set associated with the legend. Numbering of data sets starts with zero. For example,

```
plot.legend("y=2x+5", 0);
```

plot.line(x1, y1, x2, y2)

draws a straight line between the two end points [x1, y1] and [x2, y2]. For example,

```
plot.line(-10, 150, 10, 250);
```

plot.lineType(num, lineType, lineWidth, "grey")

specifies a line type. The first argument num specifies the data set, to which the line type, width, and color apply. The second argument lineType is an integer index representing the line type for drawing. Use the same value for different curves making each curve with the same style to have the same color by default. The third argument lineWidth, with an integer value, is a scaling factor for the line width. The actual line width in the plot is lineWidth multiplied by the default width. The fourth argument in the string specifies the color. For example,

```
plot.lineType(0, 1, 2, "green");
```

plot.numberLine(x0, x1, ...)

draws a direction line to connect two adjacent points on the number line. Each direction line has a vertical offset from the number line. For example,

```
plot.numberLine(x0, x1, x2);
```

plot.numberLineScatter(x, n)

plots data in array x with the n number of elements as a scatter plot with an offset on the number line. For example,

```
plot.numberLineScatter(x, n);
```

plot.outputType(PLOT_OUTPUT_TYPE_FILE, "format", "filename")

specifies the output type of the plot. By default, a plot will be displayed on the screen. For example,

```
plot.outputType(PLOT_OUTPUTTYPE_FILE, "jpg", "plot.jpg");
```

plot.plotting()

generates a plot. For example,

```
plot.plotting();
```

plot.plotType(PLOT_PLOTTYPE_FILLEDCURVES, num, "y1=-20", "color")

specifies the plot type for filling an area. The second argument num specifies the data set to which the filled curve applies. The third argument specifies an axis for filling the area. The fourth argument specifies the color to fill the area. The example below

B.22. Member Functions of the Plotting Class **CPlot**

```
plot.plotType(PLOT_PLOTTYPE_FILLEDCURVES, 0, "y1=-20", "yellow");
```

specifies that the plot fills the area with the color grey between the curve, created by the data points in the first data set, and the horizontal line $y = -20$.

plot.plotType(PLOT_PLOTTYPE_LINE, num)

specifies the plot type as a line for the data set num. For example,

```
plot.plotType(PLOT_PLOTTYPE_LINE, 0);
```

plot.point(x, y)

draws a point at the coordinate (x, y). For example,

```
plot.point(-10, 10);
```

plot.pointType(anum, pointType, pointSize, "color")

specifies the point type, size, and color for point(s).

num The first argument specifies the data set to which the point type, size, and col or apply. The second argument pointType in integer represents the desired point type. The third argument is the point size multiplied by the default size. The last argument is color for the point. For example,

```
plot.pointType(num, 7, 2, "green");
```

plot.rectangle(x, y, width, height)

draws a rectangle with the lower left corner at the point (x, y) and specified width and height. For example,

```
plot.rectangle(0, 0, 3, 4);
```

plot.scattern(x, y, n)

plots data in arrays x and y with the n number of points as a scatter plot. For example,

```
plot.scattern(x, y, n);
```

plot.sizeRatio(ratio)

sets the x and y aspect ratio for the plot. For example,

```
plot.sizeRatio(1);
```

plot.text("string", PLOT_TEXT_CENTER, x, y)

adds the text "string" at (x, y). For example,

```
plot.text("x", PLOT_TEXT_CENTER, x, y);
```

plot.ticsRange(axis, incr)

specifies the incremental value for tick marks for an axis.

```
plot.ticsRange(PLOT_AXIS_X, 1);
plot.ticsRange(PLOT_AXIS_Y, 5);
```

plot.title("plot title")

adds a title, specified in a string, to the plot. For example,

```
plot.title("Ch plot title");
```

B.23 Quick Animation

B.23.1 QuickAnimation Keywords

`animate` `circle` `fixture` `line` `point` `polygon` `rectangle` `text` `title`

B.23.2 QuickAnimation Reserved Words

`angle` `dashed` `dotted` `fill` `linestyle` `linewidth` `pen` `reverse`

APPENDIX C

Glossary

- **sign**: Negates the value of a number. Used to signify a negative value.
- **subtraction operator**: Operator that gives the difference between two values.
- \ " **double-quote-character escape sequence**: Produces a double quote. The active position is moved to the next character.
- \ \ **backslash-character escape sequence**: Produces a backslash. The active position is moved to the next character.
- \a **alert escape sequence**: Produces a visible or audible alert.
- \n **(newline escape sequence)**: Moves the active position to the initial position of the next line.
- π : The ratio of a circles circumference to its diameter.
- %c: A conversion specifier used in **printf()** to print a character or in **scanf()** to get a character.
- %d: A conversion specifier used in **printf()** to print an integer or in **scanf()** to get an integer.
- %lf: A conversion specifier used in **printf()** to print a decimal or in **scanf()** to get a decimal.
- %s: A conversion specifier used in **printf()** to print a string or in **scanf()** to get a string.
- * **multiplication operator**: Multiplies two numbers or expressions together.
- *= **multiplication assignment operator**: Compound assignment operator for multiplication.
- / **division operator**: Divides two numbers. If both numbers are of type integer then this will only return an integer value.
- /= **division assignment operator**: Compound assignment operator for division.
- #define **preprocessing directive**: Used for defining macros at the beginning of the program.
- #include **preprocessing directive**: Used for including header files at the beginning of the program.
- % **modulus operator**: Returns the remainder of a division operation.
- %= **modulus assignment operator**: Compound assignment operator for modulus.
- & **address operator**: Used in the function **scanf()** to assign a variable name to the received information.
- && **logical AND operator**: The logical operator used to check whether both the conditions of its two operands are true.
- _fpath: The system variable on which a function is searched.
- ! **logical negation operator**: Negates the current Boolean value. Makes a true value false and a false value true.
- ! **logical NOT operator**: Negation of a logical value. True becomes false and false becomes true.
- != **inequality operator**: The inequality is false if and only if the operands are exactly equal.
- || **logical inclusive OR operator**: Logical operator represented by two vertical lines. If either or both of the operands are true, then the operation will be true.
- **decrement operator**: Reduces the value of a variable or number by one.
- < **less than operator**: Test if the value of the left expression is less than that of the right.
- <= **less or equal operator**: Test if the value of the left expression is less than or equal to that of the right.
- > **greater than operator**: Test if the value of the left expression is greater than that of the right.

>= greater or equal operator: Test if the value of the left expression is greater than or equal to that of the right.

+ addition operator: Operator used to add two numbers or expressions together.

+ sign: Used to signify a positive value.

++ increment operator: Increases the value of a variable or number by one.

+= addition assignment operator: Compound assignment operator for addition.

= assignment operator: Used to assign value to a variable.

-= subtraction assignment operator: Compound assignment operator for subtraction.

== equal-to operator: Used to test the equivalence of two values.

abbreviations: A shortened word or phrase. Used in ChIDE to quickly insert a block of text using only a short key phrase.

Abort: A debug command used to stop a program that has failed or is taking too long to complete.

actual argument: The arguments passed to a function while the function is called.

address operator: A symbol used in the function `scanf()` before the variable name that obtains the address of the variable, which allows the value from the users input to be stored.

algorithm: A step-by-step method to perform calculations.

algorithmic error: An error in a program due to incorrect logic, values or formulas. This type of error can not be detected by ChIDE.

ALU: Arithmetic Logic Unit. The fundamental part of the computer which performs the arithmetic and logic operations.

AND: The logical operator used to check whether both the conditions of its two operands are true.

application software: Software designed to help the user perform specific tasks.

arithmetic and logic unit: See ALU.

arithmetic operators: The Ch operators that represent the four arithmetic operations are `+`, `-`, `*`, `/`.

array of characters: See array. An array of characters refers to an arrangement of characters (letter of the alphabet).

array: A systematic arrangement of information that can be indexed.

arrow keys: Keyboard keys that allow you to repeat previous commands in the Ch Command Shell.

arrow(): See `plot.arrow()` in class **CPlot** Appendix

assembler: A program that turns assembly language into machine language.

assembly language: Computer language that uses familiar symbols like 'add' or 'sub' to represent the 0's and 1's from machine language.

assignment operators: Also known as the equal sign. The assignment operator is used to assign a value to a variable.

associativity: Used to decide which operation is performed first when two or more operators have the same precedence. Associativity reads left to right.

axisRange(): See `plot.axisRange()` in class **CPlot** Appendix.

break: A statement that provides an early exit from for and while loops, and switch statements.

Breakpoint: An intentional stopping of a program. Useful in debugging to find where errors are occurring.

bugs: An error in a computer program.

C: The most popular computer programming language used in college and industry.

cache memory: A small amount of memory that can be accessed rapidly and stores data from the most frequently used main memory locations.

called function: The function that is currently being called by the program.

calling function: The function currently calling for the particular statement to be executed.

case: Part of a switch statement. Each switch statement can have as many cases as necessary but they each must check a different value.

cd: A command used in the Ch command shell that takes the user to their home directory.

central processing unit: See CPU.

Ch: A user-friendly interactive C/C++ computing environment especially designed for absolute beginners to learn computer programming and problem solving with computers.

char: A variable of character type in C that can be used to store characters such as letters and punctuation.

character array: An array containing only characters.

character constants: Can be written as one character with single quotes around it.

character string: A sequence of characters (letters, numbers, and symbols) enclosed in a pair of double quotes, such as "Hello, world".

ChIDE: An integrated development environment used to development computer programs using C/Ch/C++ languages.

circle(): See plot.circle() in class **CPlot** Appendix.

class: A group of specific functions and data that are related and used for a specific task.

command shell: A Command Shell where single line executions can be performed.

Command Shell: A window that displays the current directory being used and allows you to enter commands.

computer hardware: The physical, tangible, part of the computer.

computer software: A collection of computer programs which can be loaded into main memory and executed.

computer: An electronic machine that stores and accepts data from users, processes preprogrammed operations upon that data and displays an output to the user.

Continue: A debugging command that allows the user to execute a function until it comes across a break point.

control unit: Part of the CPU which directs the components of a computer at the lowest level.

conversion specifier: Symbols used to print numbers or variables of a specific data type using the functions **printf()** and **scanf()**.

cos(): Function that computes the cosine of an angle (in radians).

counter-controlled repetition: An integer variable put in the controlling expression of a while loop which controls the repetition.

CPlot: A class used in Ch that allows the user to graph points and functions.

CPU: Central Processing Unit. The portion of the computer that carries out the instructions from the computer program.

data2DCurve(): See plot.data2DCurve() in class **CPlot** Appendix.

dataFile(): See plot.dataFile() in class **CPlot** Appendix.

dataSetNum(): See plot.dataSetNum() in class **CPlot** Appendix.

debug bar: The list of commands/icons on the ChIDE program that allows you to debug a program.

Debug Command Pane: The small bottom right window in ChIDE that allows you to change the values of your variables in the middle of running your program in debug mode.

Debug Commands: Commands that allow the user to manipulate the debugging process.

Debug Console Window: The window that displays output and receives user input while debugging.

Debug Pane: The section of windows that allows the user to view the value of variables during debugging.

debug: The process of finding, understanding, and fixing errors in a computer program.

debugger: A computer program that is used to find errors, or bugs, in other computer programs. In ChIDE, this is integrated into the application.

debugging: The process of eliminating bugs (errors) from the source code of a program to ensure that it functions correctly.

declaration: The section of a program that declares the variables.

default: The expression executed if no previous cases are met. The default option in the switch statement is optional.

disassembler: A program that turns machine code back into assembly language.

double description= A variable type that represents a decimal number in Ch.

Down: ChIDE debug command to move down to the calling function.

dual programming: A collaborative learning technique pioneered by the UC Davis C-STEM center where two students work together, each with their own computer to complete a programming assignment. Both partners must complete an assignment before either one is allowed to move on to later exercises. As they are working, partners compare their source code, discuss the differences, and support each other in the debugging process.

Editing Pane: Using ChIDE, the edit pane allows the user to edit programs.

enhanceText(): See plot.enhanceText() in class **CPlot** Appendix.

else: One of the control keywords to signify a conditional.

else if: Similar to the if statement but an additional command will be executed if the loop returns a false value.

error message: Information displayed when the computer finds something unexpected, can not interpret a specific line of code or fails to complete a requested operation.

escape characters: Escape codes beginning with the backslash character.

exit code: A numerical value that represents whether or not the program has been successfully executed.

expansion: The block of text that will replace the abbreviation.

expr(): See plot.expr() in class **CPlot** Appendix.

external memory: Memory stored outside of the computer such as a flash drive or external hard drive.

feof(): Returns a non-zero value when end-of-file (EOF) indicator has been previously detected.

fgets(): Function used to read a line from a file.

field width: The size of a field in which data is printed.

file extension: The last two or three letters of a computer file's name, which identifies the file type and which programs to use with the file. Common examples include .exe, .doc, and .pdf

file format: A particular way that information is tagged and stored in a computer file. There are many different types of file formats including: word processing, music, and video.

FILE: Data type that maintains information about the stream.

firmware: Computer programs stored in ROM that remain in the computer even after it is powered off.

floating point numbers: Numbers used when a decimal is needed.

flowchart: A visual way to organize structured programs.

for loop : In a for loop expression 1 is evaluated, then if expression 2 is true the statement is executed and expression 3 is evaluated. The loop exits when the condition is false.

for: C reserved word to start a for loop.

formal argument: The arguments inside a function.

fplotxy(): High-level plotting function with its prototype defined in header file **chplot.h**. Useful for generating two-dimensional plots.

func2D(): See plot.func2D() in class **CPlot** Appendix.

function file: A Ch file that contains only one function definition.

function prototypes: A declaration of a function that declares the return type and types of its parameters.

function: A self contained block of code in a function that can be called on to do specific functions.

grid(): See plot.grid() in class **CPlot** Appendix.

header file: A file that contains reusable code defining classes, member functions, variables, etc. Adding a header file into source code is done at the beginning of the program and starts with **#include <header>**. For example, when we wish to create a plot using the **CPlot** class member functions, we must have the statement **#include <chplot.h>** at the beginning of our code.

home directory: The file that contains all of the documents, bookmarks, music, etc, specific to that user. For windows, this file is usually located at C:/Documents and Setting/username.

I/O: Input/Output refers to data received by a program (input) and the data produced by a program (output).

IDE: See Integrated Development Environment.

if: A common loop that is executed only when the returned value is true.

if else: See **else if**.

inclusive: Covering or containing all items within a given set.

increment and decrement operators: Operations that either add or subtract one from the returned value.

increment: The amount between tic marks on a plot.

initialization: The section of a program in which variables are assigned values.

initialize variables: A single expression that defines a variable type and assigns it a value.

input: The data received by the program either from the user or by reading some data already stored on the computer.

input/output: The communication between a computer program and the input/output devices such as keyboards and monitors.

Input/Output Pane: Using ChIDE, the input/output pane accept the user input and displays the results of running a program.

int: The Ch reserved word that declares a variable representing an integer.

Integrated Development Environment: An application created for program development that combines a source code editor, compiler and interpreter, and debugger all into one application.

interpreter: A program that executes programs written in a programming language directly without compilation.

iteration statement: Cause statements to be executed zero or more times.

keywords: A word or identifier with a particular meaning.

label(): See `plot.label()` in class **CPlot** Appendix.

legend(): See `plot.legend()` in class **CPlot** Appendix.

line(): See `plot.line()` in class **CPlot** Appendix.

linear search: See sequential search.

lineType(): See `plot.lineType()` in class **CPlot** Appendix.

Locals: A tab on the debug selection bar, the **Locals** allows the user to see all the variables the program is using and how they change throughout the debug progression.

logic error: See algorithmic error.

logical operators: Compare Boolean expressions and return a Boolean result.

loop: Executes a statement repeatedly until the controlling expression returns a false value.

M_PI: A macro that represents the constant pi.

Mac OS X: The current operating system used by Apple Macintosh computers.

machine code: The lowest-level computing language that consists of 0's and 1's.

machine language: See machine code.

macro: A symbol or name that represents a predefined value.

main memory: Used to install both programs and data.

main(): The section of the program where execution begins.

mean: Also called the average, defined as the sum of all elements divided by the number of elements.

member function: A function that is associated with a specific class. For example, the member function **line()** is associated with the **CPlot** class and must be called using `plot.line()`.

memory: Digitally stored computer information.

microprocessor: Executes the instructions of a program. The CPU is often referred to as a microprocessor.

minimum: The lowest value of the set.

modulus operator: Operator represented by the 'percent sign'. Returns the remainder of a division operation.

modulus: The remainder of a division operation.

NaN: See Not-a-Number.

nan: See Not-a-Number.

nested loops: A loop inside of another loop.

newline character: Written as `\n`, the newline character is used in the function **printf()** and acts as a return or enter character and puts the following text on the next line.

Next: A debug command that allows the user to step through the code line by line but steps over, or does not go into, any function call.

Not-a-Number: **nan** or **NaN**, an abbreviation for Not-a-Number, is returned if an expression reduces to an undefined or imaginary quantity, such as the square root of a negative number.

NULL: Value used to indicate that a particular data value does not exist in the database.

operand: The variables and numbers used with the operator.

operator: A symbol used to manipulate the value of data by performing commonly used tasks, such as addition, subtraction, multiplication, and division, as well as comparing values.

operators precedence: Order of precedence among operators. Operator precedence determines which operation will go first in an expression.

OR: Logical operator represented by two vertical lines. If either one or both of the operands are true then the operation will be true.

Order of Operations: The order in which all expressions are evaluated. From left to right you solve Parentheses, Exponents, Multiplication/Division, and then Addition/Subtraction.

output: The information transferred to the user by an output device, such as a screen, as a direct result of some function.

Parse: A debug command in ChIDE used to check the syntax error of the program without it being executed.

- pass array:** Passing a declared array into a function.
- plotting():** See `plot.plotting()` in class **CPlot** Appendix.
- plotType():** See `plot.plotType()` in class **CPlot** Appendix.
- plotxy():** A high-level function to plot data in arrays.
- point():** See `plot.point()` in class **CPlot** Appendix.
- pow():** A function that evaluates exponential expressions by the statement `pow(base, exponent)`.
- precedence:** The ordering of operations from most important to least important.
- precision:** Specifying the number of decimal places displayed in a decimal number.
- printf():** The Ch function that instructs the program to print text on the screen.
- processing:** The section of a program which runs calculations based on the variables and their values.
- program:** A set of instructions written for a computer to complete a specific task.
- prompt:** Indicates that the system is in a Ch shell and is ready to accept input from the keyboard.
- punctuators:** A symbol that has independent syntactic and semantic significance.
- Pythagorean theorem:** The theorem that relates the three sides of a right triangle by the equation $a^2 + b^2 = c^2$, or the sum of the two legs squared is equal to the square of the hypotenuse.
- RAM:** Random-access memory is a modern form of computer data storage. This memory can be read and written to at any time.
- random access memory:** See RAM.
- range:** In Ch, range represents the beginning and ending numbers shown on each axis in a chart. As a mathematical word, range means specifically the y or output values that are produced by a specific function.
- read-only memory :** See ROM.
- rectangle():** See `plot.rectangle()` in class **CPlot** Appendix.
- registers:** A small amount of available memory as part of the CPU.
- relational operators:** An operator that tests the relation of two quantities. The equal sign, greater than or less than signs are all relational operators.
- remainder:** The amount "left over" after division is performed.
- remvar:** A Ch command that removes a variable from the system allowing the name of the variable to be reused.
- repetition statement:** Allows the user to execute a command many times. Often referred to as loops.
- reserved words:** Special words in Ch that have specific meanings and can not be used as variable names. Some examples are int, double, and remvar.
- return:** A statement used in a function to send a value back to the original program that called the function.
- ROM:** Read-only memory is a type of storage in computers and other electronic devices. ROM is pre-loaded with programs and data that never change.
- Run:** A ChIDE command that executes a program by having the interpreter read the code and provide an output at the bottom of the ChIDE window. Function key F2 will also execute a program.
- runtime error:** An error that occurs during the execution of a program that causes the program to either freeze/crash or continue in an unexpected manner.
- scanf():** The Ch function that allows for data input into a program by the user.
- scattern():** See `plot.scattern()` in class **CPlot** Appendix.
- scatter plot:** A graph of points that may or may not represent a relationship between the input (x) and output (y) values.
- scripting language:** A programming language that allows control of one or more applications.
- search:** The process of finding a value unknown to the user. See sequential search.
- selection statement:** Statements that are executed if a condition is met.
- sentinel value:** A specific value used to indicate the continuation or end of data entry.
- sentinel-controlled repetition:** An application where the number of repetitions is unknown and a sentinel value is used to determine the end of data entry.
- sequential search:** An algorithm for searching, which checks every element of a list one at a time in sequence until a match is found.
- sequential statement:** Statements that are executed in the order they are written.
- sin():** Function that computes the sine of an angle (in radians).
- single board computers:** A complete computer built entirely on a single circuit board.

sizeRatio(): See plot.sizeRatio() in class **CPlot** Appendix.

source code: The plain text that contains the instructions for a program.

sqr(): The function that returns the square root of number.

square root function: See **sqr()**.

rand(): Sets the seed for the pseudo-random number generator.

Stack: ChIDE debug command which displays functions and program names with the corresponding stack level.

stackvar: A Ch command that allows you to view all declared variables and their values in the Command Shell.

Start: A debug command used to begin a program in debug mode.

statement: Allows programs to execute different tasks based on the results of relational and logical operations.

stdio.h: The header file that contains all the input/output declarations and function prototype. The functions **printf()** and **scanf()** are part of the header file **stdio.h**.

Step: A debug command used to execute the program line by line to identify errors. This command is different than the command Next, as it does go into the function when reads a function call.

Stop: A ChIDE command used to end a program before it has finished executing. Normally this command is used when a program is taking longer than anticipated and the user suspects an error.

string: A sequence of characters enclosed in double quotes, as in "xyz".

structured programming: Incorporating selection and repetition statements into programs. This may include if and switch statements as well as for and while statements.

supercomputers: A computer at the forefront of technology, generally equipped with the most memory and fastest processing speeds available.

switch: A common selection to handle multi-way decisions with integer or character values.

syntax error: An error in a program due to punctuation.

system software: Software designed to operate the computer hardware (monitor, keyboard, mouse, etc).

tan(): Function that computes the tangent of an angle (in radians).

termination: The section of a program in which the final output is given.

text(): See plot.text() in class **CPlot** Appendix.

tick marks: The interval between units on each axis in a chart.

ticsRange(): See plot.ticsRange() in class **CPlot** Appendix.

title(): See plot.title() in class **CPlot** Appendix.

Unix: Another operating system similar to Microsoft Windows. Unix contains Linux, Solaris, HP-UX, AIX, FreeBSD and Mac OS X operating systems.

Up: A debug command used to change the Stack to the calling function.

variable: A symbol that can represent any given numerical value.

variable length array: an array with number of elements determined at runtime.

Variables: A local variable is a variable given local scope. Such as a variable defined within a function.

void: Data type for functions without arguments and return values.

while loop: A control loop that continuously cycles while the condition is true. This can be thought of as a repeating if loop.

while: C reserved word which indicates the start of a while loop.

Windows: The most popular operating system for the PC developed by Microsoft.

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