

Programming Practice Python 2023

A collage of Python keywords arranged in a grid-like pattern. The words are colored in various shades of brown, red, blue, green, and orange. In the center, the word "Python" is written in a large, bold, green font.

1

These are reserved Python keywords. Faded words will not be covered in this book.

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0. Foreword

This textbook was written for a (Python) programming exercises course as part of Kyoto University's Liberal Arts and Sciences courses.

0.1 Learning goals of this chapter

The objectives and goals of this course are as outlined below.

0.1.1 Objectives

Python is a programming language that has many practical uses and is easy for beginners to learn. In recent years, its use in academic research has steadily increased. In this course aimed at beginners, students will learn to program using Python through various exercises.

0.1.2 Goals

- Students will learn the fundamentals of how to use Python to execute programs.
- After learning about the functions and formats of the fundamental components of a Python program, students will be able to use the examples to put together their own programs.
- Students will be able to design, implement, and test their own simple Python programs.

0.2 Reasons for writing an entirely new textbook

This text was based on the courses from the 2018-2022 academic years. There are already a large number of introductory texts for Python, however, due to the reasons detailed below, it was decided to add yet another text into the mix.

- This course does not aim to introduce the reader to Python, but rather to teach students how to write (to become able to write) their own programs in Python. Many texts have the tendency to merely be an introduction to the language itself.
- For beginners, learning a programming language is simply the overcoming of various mistakes. Even mistakes that seem severe when you are a beginner are often completely forgotten once you have gained some programming experience. Through practical exercises, this course aims to keep the spots that beginners tend to make mistakes in mind, and to tailor the explanations in a manner that helps them overcome these mistakes.
- Related to the above, learning a programming language consists of writing and executing actual programs by yourself. This text includes directions for actual programming exercises.

While this text serves as a guide for beginners that explains the fundamentals of programming using Python, it is not a comprehensive introduction of Python's language specifications. It is recommended for students to prepare other learning materials on Python and take them to classes.

0.3 Humanities majors: you can do it!

It seems that there are many humanities students that think of programming as something that should be left for the science majors. Programming is indeed a technique to control the complex machines known as computers, and source code can often look like numerical formulas. However, in actuality, programming merely delegates to machines work that humans can perform themselves. It is important to firmly understand the actions performed by humans because in this respect humanities students can gain an edge. Many humanities students have taken this course in the past and received passing grades.

0.4 Regarding the organization of this text

This text was organized based on the courses from the 2018-2020 academic years. As such, it is structured such that you can work through the exercises in order from the front of the book. Topics from the classes that represent a digression from the topic at hand are compiled as independent “Columns.”

0.5 Notation

It is most effective for students to learn using a two-pronged approach. One side of this approach will see students learning by testing simple commands line by line in an interactive environment known as the Python shell. The other side will have students write larger programs (scripts) in an editor and execute them as a batch.

Features that students are to try out in the Python shell are represented in the text using the red K2PFE font seen here:

`a = 1 + 2`

The results obtained from executing these commands are shown in blue as seen here:

`3`

Please try these out for yourself as you learn.

On the other hand, larger programs will be shown using the table format with three (or two) columns seen below. Input the source code into the editor and execute the program to see the results. In this representation, a character '`\`' is placed instead of space '' so as to make them visible.

Row	Source code	Notes
1	<code>a=_1+_2</code>	' <code>\</code> ' is used instead of space '' ,
2	<code>print(a)</code>	

Notices in typing actual programs referring the source code lists:

- Spaces in the source code are replaced with '`\`' so as to make them visible.
- Ordinarily fonts in Windows, a glyph of yen (¥) is used for backslash code (`\`). K2PFE font uses a glyph of backslash (`\`) instead.

0.6 Warning regarding copying and pasting

The source code that appears in this text was formatted in Word before being converted to PDF

format. In the PDF document, spaces are not saved, and there are instances in which the characters will be automatically changed. As such, please be aware that there are instances in which simply copying and pasting from the PDF will lead to program errors.

0.7 Edits for later versions (2023 and later)

In the 2023 version, some misprints were corrected, some hard-to-read portions were edited, and some additional explanations given during the 2022 course were added. The square root calculation that was used as an exercise in Chapter 3 has been improved and added as its own section in Chapter 4. In addition, portions on Python program termination were added to the chapter on control flow (Chapter 6), and various practical exercises covering material through Chapter 7 were added as Chapter 8. Furthermore, ways of defining the turtle shape in the turtle graphics chapter (Chapter 10) have been added, and a simple exercise to help introduce tkinter was added to chapter 11 alongside improvements to the explanation. Image display has also been added to the widget. An example of an error that can occur during function calls was added to chapter 19.

Notes for English Version

This textbook is a translation of the Japanese version referred to as “Puroguramingu-Enshuu Python 2023 (プログラミング演習 Python 2023).” The original version cited several Japanese references. We have retained some quotes and references in Japanese.

Acknowledgements

Since the publication of the 2019 version following the 2019 academic year, we have received many helpful opinions as well as identifications of misprints. Our deepest thanks for all of those who shared their opinions with us.

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1. Computers and Programming

1.1 Learning goals of this chapter

- Understand how computers operate in general, and how programs factor in.
- Learn about the role of programming languages in programming.
- Learn about various uses and applications for writing programs.
- Learn about how to study programming.

Exercise 1-1 Motives for taking this course

Please answer the following questions.

1. Why did you decide to take this course?
2. Why do you want to learn programming?
3. Why do you want to learn Python?
4. Please indicate whether you have any previous experience with studying programming (Yes or no). If yes, how much?
5. For those with previous experience studying programming, what programming language(s) did you use?

1.2 Computers and programs

1.2.1 Machines that are run by programs

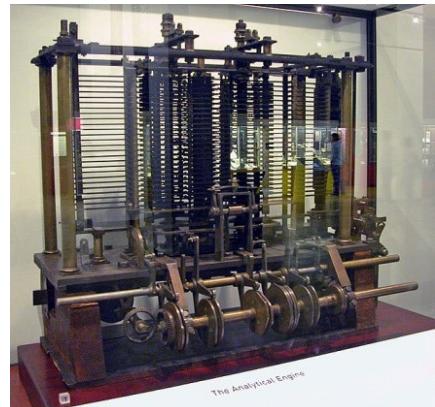
You have probably heard of the Jacquard machine sometime in a history course. Textiles are woven by passing a weft thread through a warp thread. One can weave a specific design by varying which warps are run on top of the weft and which are run beneath. A Jacquard machine is a machine that can correctly weave the thread provided it is given instructions regarding which way to run the thread in the form of paper with holes punched into it (referred to as punch cards). By binding together many punch cards and feeding them into the machine in order, one can create complex designs. In order to create a different pattern, one simply needs to swap out the punch cards.

One can still find Jacquard machines actively used in the Nishijin district in Kyoto, where weaving is a booming local industry. Figure 1-1

Charles Babbage (1791-1871) was an inventor from Great Britain who set out to develop a mechanized calculator. Starting with a mechanism that automatically generated number tables from sequences of differences, Babbage took inspiration from the Jacquard machine and attempted to create a mechanized calculator (The Analytical Engine) that is run by a program. Unfortunately, he was never able to complete it; however, he is viewed as a pioneer in the field of computer science for his attempts to make a mechanism that performs calculations according to a program.



Jacquard machines and punch cards
Taken at Fukuoka Weaving in Kyoto



Babbage's Analytical Engine

Figure 1-1 Jacquard machine and Analytical Engine

https://commons.wikimedia.org/wiki/File:AnalyticalMachine_Babbage_London.jpg

1.2.2 Computers are composed of “switches” that run by electricity

In Babbage's era, complex mechanical movements could only be attained by using gears or something similar. Later on, it became possible to create mechanisms that use electricity to fit in another electrical switch. One of these was to use an electromagnet to mechanically move (**relay**) an electrical contact. Attempts were actually made to use these electrical relays to make computers. However, while this works from an electrical standpoint, the mechanical movement that accompanies it was far too slow.

After this, computers were developed that utilized **vacuum tubes**. These were tubes in which electrons flowing between an electrode (cathode, anode) are controlled by the voltage applied to a different electrode placed between them. Vacuum tubes had the advantage of fast electronic movement, however, the fact that a filament was needed to add heat in order to make the cathode emit electrons meant they had short lifespans.

Following this, **transistors** were invented. Transistors are devices that enable behavior similar to that of a vacuum tube to occur within the solid matter of a semiconductor. Transistors have a long lifespan, are very small, and do not consume much electricity. At this point, computers that consisted of a large number of discrete transistors wired together were made.

Finally, **integrated circuits** were developed. These circuits are printed as an entire unit and consist of a lot of transistors and wiring on top of a single semiconductor chip. Integrated circuits are much smaller and much more cost efficient when compared to normal electronic circuits. Integrated circuit technology was then used to develop microprocessors, which are essentially the main component of a computer (all contained in a single chip). Microprocessors are the breakthrough that made cheap, small computers that anyone can use, such as PCs and smartphones, into a reality.

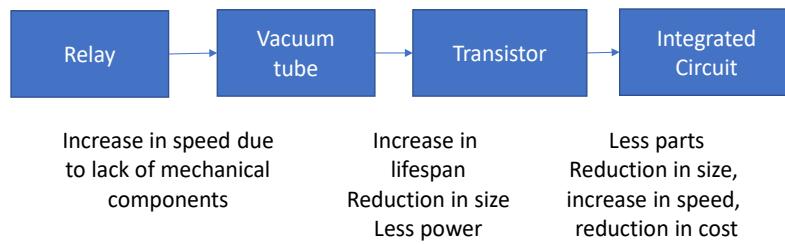


Figure 1-2 Progression of logic gates

Next, we will take a look at the amazingly rapid progression of the number of transistors that could be integrated onto a single semiconductor chip (degree of integration), which has increased by over a million times in 40 years. Technological innovations that improve efficiency by orders of magnitude effected not only integrated circuits, but storage capacity and communication speed as well. It is through technological innovations like this that you are able to use your smartphone to enjoy YouTube videos in the modern era.

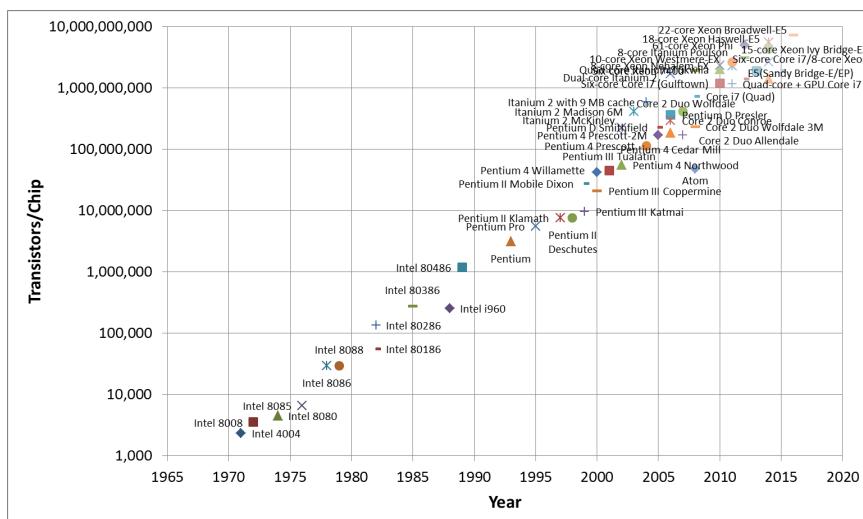


Figure 1-3 Microprocessor transistor counts

https://en.wikipedia.org/wiki/Transistor_count#Microprocessors

Plot of a selection of Intel processors (Accessed Jan. 2, 2017)

1.3 Computer structure

1.3.1 Stored-program computer

So just how do modern computers carry out complex data processing?

The actions a computer (the hardware itself) can perform at one time are very simple, and complex work like data processing is merely a combination of these simple actions. This combination of actions is expressed as a program and put into action.

In modern computers, programs are stored in memory just like the data they handle. They are read at rapid speeds and then executed. Computers that work in this manner are called “stored-program

computers.”¹ All computers used today, from the small microprocessors used in home appliances to giant supercomputers, are stored-program computers.

By changing programs according to the type of work that needs to be done, the same computer (hardware) can be used to accomplish a wide variety of tasks.

Programming is the act of writing out, in the form of a program, the data processing steps that you wish to perform.

1.3.2 The Components of Computers and Their Functions

The main components of a computer’s hardware are the CPU and the memory.

The CPU contains the following major elements of a computer.

- Mechanism(s) to take in and parse commands from the memory
- Counters that point to the memory addresses of the program(s) that are currently being run
- Device(s) to preserve data (registers)
- An arithmetic-logic unit (ALU) that functions to perform arithmetic and logical operations on variables

The fundamental operations that a computer can perform are the following simple tasks.

- Configure a program and data used in the program in the memory (by some method).
- Provide the CPU with an execution start location for the program
- The CPU repeats the following:
 1. Reads one step of the program from the memory and performs calculations or move data according to the instructions.
 - ✧ The result of the calculation can also be stored in the memory.
 - ✧ Input/output can also be performed.
 2. The CPU advances the instruction being executed to the next location.
 - ✧ In some cases, the executed location can change based on the program.

¹ In an early computer called ENIAC, calculation settings were not done in stored-program fashion; rather, they were set by altering the wiring of the cables. However, upon developing its successor, EDVAC, the stored-program method was proposed. As the report proposing it was submitted by von Neumann, it is sometimes referred to as the von Neumann architecture.

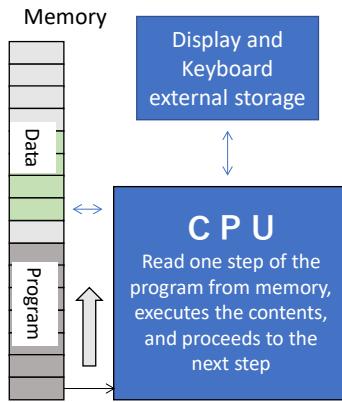


Figure 1-4 Computer (hardware) organization

In order for the hardware (CPU + memory) to be able to easily process commands at high speeds, the commands that can be executed in actual computers are limited to extremely simple ones. These commands are referred to as machine code.

1.4 Programming languages

Programming complex actions in machine code is profoundly difficult. Programming languages were the solution devised in order to solve this problem, and they are created in the following manner.

- Determine rules that enable you to write programs in a manner that are more easy-to-understand for people (**decide upon programming language specifications**). Generally something that looks less like machine code and closer to numerical formulas
- Create a program that can execute any program (source code) written in accordance with the rules of the language (**build a language processor**)

Essentially, you write a program in the programming language, and the written program is executed using the language processor. In simpler terms, a language processor + a computer effectively yields a virtual computer that can execute any program written in a programming language.

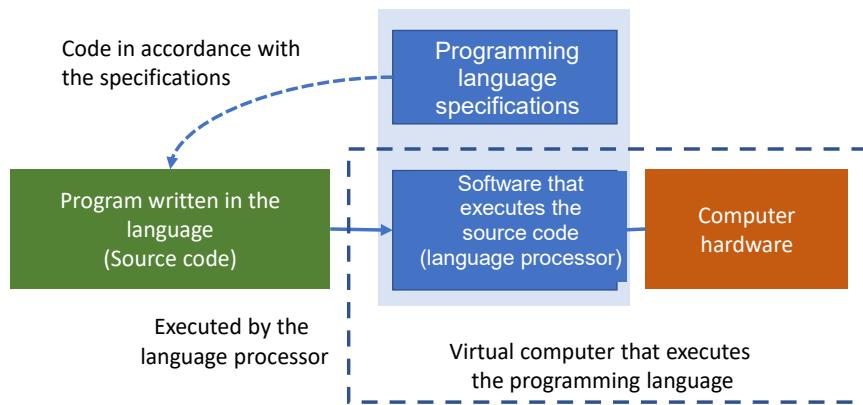


Figure 1-5 Programming languages and language processors

1.4.1 Various programming languages

As shown in the table below, many programming languages have been created and are in common use.

FORTRAN	COBOL	ALGOL	Pascal	PL/I
BASIC	C, C++, C#	Java	Go	Swift
Perl	Ruby	Python	JavaScript	LISP
Haskel	R	Matlab	ProLog	Scratch

In addition, there are many things that strongly resemble programming languages that are often used together with them. For example, HTML which codes for web pages, CSS which codes for the page's style, XML and JSON which code for data, and SQL which codes for database inquiries.

Why are there so many programming languages being used? Why are they not just all combined into one?

The advancement of computing requires the overall improvement of the programs that are developed. Consequently, the ways of thinking required to effectively code as well the programming languages based in these ways of thinking developed over time. The desire to write programs more easily, more quickly, and more securely is ever-present. There is a demand for programming languages that are specially tailored to specific uses. New programming languages have been developed and the specifications and language processors for specific programming languages have been altered with these facts in mind.

On the other hand, the use of software developed in a certain programming language as well as the programmers who wish to code in that language create demand for its continued usage.

Discontinuing old languages can be difficult. FORTRAN, a programming language that is used in scientific computing, is the oldest programming language, yet still sees use following various modifications.

Some programming languages have been developed by software companies, while others have been created by individuals or as a community effort. Certain programming languages are developed by companies strictly for-profit and require that you buy their language processors. Additionally, there

are cases in which languages are developed due to the needs of a company and the language processors are distributed freely with their source code made public.

1.4.2 Composition of a language processor

There are a few different ways to compose programs (language processors) that can process and execute programs (source code) written in a programming language. The three variations are as follows:

1) Compiler

Executes the source code and then translates (compiles) it into machine code. The resulting machine code is then executed. Compiling takes time, however the compiled executable program (machine code program) can be executed very quickly.

2) Interpreter

Interprets the source code line by line, simulating the operations. Execution speeds can be slow as interpreting the source code takes time; however, interpreters are so flexible that they can be used for various purposes such as interactive usage.

3) Intermediate representation (IR)

Lying somewhere in between compilers and interpreters, IR translates the source code not into the CPU's machine code, but rather into machine code (intermediate representation) for a hypothetical virtual computer used for that language. This IR is then executed using an interpreter (virtual machine). Java and Python use this type of translator.

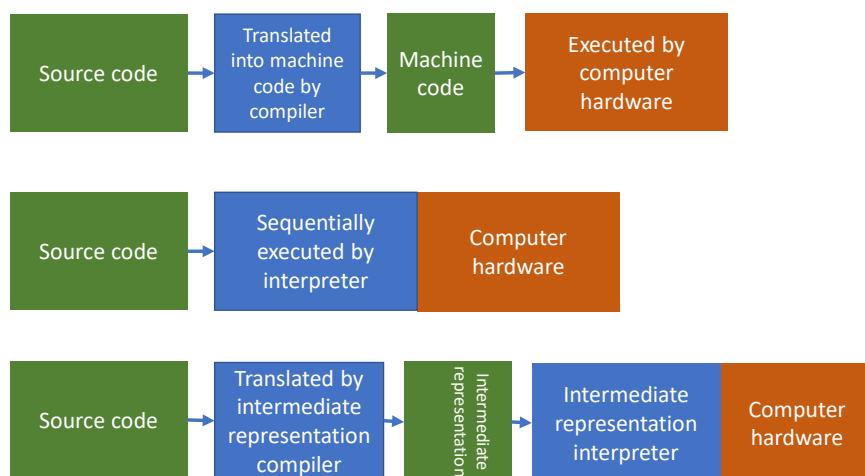


Figure 1-6 Types of language processors

1.5 Python

1.5.1 History of Python

In 1989, Guido van Rossum began working on Python. Version 2.0 was released in 2000, and version 3.0 was released in 2008.

Note: Python version 3 is not backward compatible with version 2 (version 3 does not contain the specifications of version 2). As such, both versions tend to be run concurrently in order to ensure that programs written with version 2 can run properly.

Note: Python generally comes pre-installed on Mac and Redhat Linux, but in some cases version 2 is the one that is installed. In order to use version 3, you may need to install the version 3 language processor separately and ensure the correct version is being used at all times.

1.5.2 Characteristics of Python

- Easy for beginners to learn yet capable of advanced programming
- Can be used for a wide variety of applications
- Libraries for scientific computing (NumPy, scipy, matplotlib, pandas, etc.) are being developed by many people.
- In recent years, interest in data science and artificial intelligence (machine learning) techniques has increased dramatically. Python has been growing in popularity due to its abundant libraries for these applications.

1.5.3 Python distribution packages

There are several Python language processors in development, and as a result there are many packages that contain different combinations of things such as development environments, and libraries. For this class, we will use the following two packages:

- Python: A distributable from the designers of Python; uses CPython, which is coded in the C language, as its language processor.
- Anaconda: Contains modules for scientific computing wrapped into CPython as a single package. We assume that you will be using this package in this class.

1.6 Various applications

There are likely some of you who have specific applications in mind as reasons for why you want to learn Python. Let's look at some of its various potential usages.

1.6.1 Applications for personal computers (PCs)

Programs that run on PCs can largely be divided into two groups based on their operating environments.

- CUI programs. These programs operate via the Windows command prompt or something similar, take text input from the keyboard, and output text onto the screen. These programs are relatively easy to learn due to the simplicity of input and output, but they also tend to not be very user-friendly.
- GUI programs. These programs operate within a window and are controlled via buttons or similar objects within the window. GUI programs enable the user to operate the program in a manner they are likely already accustomed to, and images can also be included. However, the number of things that you have to program is usually much higher. Reading and writing files, network management, and many other actions require similar programming in both CUI and GUI programs.

A few examples of using potential applications are given below.

- Scientific computing and numerical simulations
- Data processing and analysis of numbers, strings of text, and images
- Video games and graphical works
- Automatic data collection from websites (called web scraping)

1.6.2 Other applications

- Smartphone applications
- Programs that operate on web servers or other servers on networks
- Programs that operate in coordination with electronic circuits. Raspberry Pi is a small computer that runs on Linux and Python that was developed for this purpose.

1.7 How to learn programming

1.7.1 Reasons why programming is difficult

Computer programming can be difficult for a variety of reasons. Understanding how and why it is difficult will likely help you in your journey to learn programming.

1) The concepts that compose programming languages are hard to understand

Even the natural languages that you use every day require complex grammar and diction in order to express complex ideas. Similarly, programming languages require you to employ various concepts and contrivances in order to skillfully express complex programs.

There is no need for you to try to understand all of these concepts at once. You can **gradually work your way up from the simplest ones**.

2) Unable to deal with errors

In programming, various errors (called bugs to liken them to metaphorical bugs eating away at the program) arise from mistakes and typos. It is important to go into programming with the

understanding that you will frequently encounter bugs, however:

- You should understand that accurate typing in accordance with the syntax of the source code is necessary.
- Syntax errors aside, there will be times when misconceptions about the program lead to it operating in a manner that defies expectations.
- The vast majority of bugs are due to human error. It is important for you to gradually build up experience recognizing and dealing with various errors.
- Dealing with errors involves backtracking from the result of “an error has occurred” to the root problem that is causing it. You will need to come up with various hypotheses about the cause of the error that correspond to the type of error you have encountered and then investigate to determine whether or not it is actually the cause.
- There are times when the computer’s response (when the computer has been rendered unable to process) does not match up with the actual mistakes in the program.

3) Unable to add the feature that you wish to implement

Even if you learn the components that make up a programming language, it can often be difficult to figure out how to combine them in a manner that produces the desired result. Just like how even if you know how to use a hammer and saw, you cannot build a house unless you know how a house is built.

It is necessary to thoroughly analyze what you wish to do in plain words and then to write the program after getting a clear understanding of the procedure. You can start by learning from examples of relatively simple applications and gradually working your way up.

4) The program becomes too complicated to understand

When a program becomes very long it gets more and more complex and it can suddenly become difficult to make sense of just what you are programming. For beginners, even a 100 line program can seem very daunting. Learners should work towards a goal of writing a 100 line program as they gradually pick up methods of coding in a way that makes longer programs much easier to navigate.

5) There are techniques for writing large programs

Some of the largest programs in the world can reach hundreds of millions of lines. Naturally, a single person cannot write these programs on his/her own, nor can he/she know all of the lines of code they contain. There are certain methods and tools for writing such huge programs. Some examples can be seen below.

- Create a thorough plan for the entire program
- Partition it into modules so that the work can be divided
- Write and test the program module by module.
- Test the entire program after putting it all together

Once you are able to write programs of around 100 lines, it is a good idea to challenge yourself to write a larger program with these techniques in mind.

1.7.2 How to learn programming

As with all subjects, it is essential for you to learn how to learn.

- How do you pick up a foreign language?
- How do you learn mathematics?

Programming is the skill of actually writing programs with your own hands, so in that sense, it is similar to other practical skills like math and foreign languages. However, programs can be tested as you write them, and they can have all sorts of interesting applications, so they should not be as intimidating as math or foreign languages.

1) Motivation: you should work with things that interest you

- Your motivation for learning is critical if you wish to be able to persist in their studies. There are many people who say vague things like “I want to learn how to program.” However, this alone is too vague to serve as a concrete goal, which makes it easy for you to lose motivation. Fixating on something more concrete, even something more difficult like “I want to make a game” is usually more effective. Choosing a certain subject or application that you are interested in makes it easier for you to preserve your motivation to learn.

2) Lots of reading and writing is fundamental to learning programming

- Type out and execute a bunch of exercises.
 - “Understand through doing” rather than “do after understanding”
 - Learn the patterns in vocabulary, symbols, and notations. It’s important to learn common patterns as a single unit.
 - Typing source code more quickly and accurately helps raise your learning efficiency.

3) Reading aloud/Read while interpreting

- Reading the symbols in the source code out loud while interpreting their meaning is an important ability that helps to facilitate **effective communication** in class.

4) Tinkering: play around with programming exercises.

- Make small changes to programs found in exercises to gain a feel for what is possible.
- Try combining multiple exercises. Doing so will help you understand what adjustments are necessary when combining programs.

5) Tracing

- Follow a program manually by hand in order to see how it will function (called tracing)

6) Become able to deal with errors

- When programming, you are constantly dealing with errors. Becoming able to do so is an important goal in and of itself.
- Actual programming requires you to be able to deal with unforeseen errors, but **intentionally**

writing programs that contain errors in order to see what happens can be an effective way to gain experience.

- Read the error messages. There are many beginners who do not read the error messages that are displayed when they encounter an error. Error messages can definitely seem difficult to understand, but they are telling you where or what the error you have encountered is. Error messages for errors that you have intentionally caused should be relatively easy to understand, so please try to familiarize yourself with them.

7) Look up information

- You should strive to become able to search for information on programming via topic or method. A few methods for doing so are given below.
 - Learn how to use various libraries and advanced programming concepts.
 - Learn about tools that support programming.
 - You can look up information in books or on the internet.
 - Ask others for help with things you don't understand. This requires the communication skills to be able to ask for help when you need it.

1.7.3 Characters used in programs

Most programming languages are designed with English as a basis, so you will need to keep this in mind when dealing with characters and character encoding. Reference the column titled "Programming & Japanese - The Never-ending Battle against Character Encoding."

- Python (and most programming languages) uses **half-width alphanumeric characters**.
- Full-width characters are only used in strings and comments¹.
- Python distinguishes between uppercase and lowercase letters (it is “case sensitive”).
- Various symbols are used in programming.
 - It is important to learn the **appropriate names** for these symbols,
 - not just their **location on the keyboard**. This ensures you can communicate about these symbols with others.
- In addition, you will need to be able to press keys, such as the C key, while holding down the Ctrl key. This is written as Ctrl-C. The same is true for the Alt key.

¹ While variable names in Python can use kanji, this is not the case for many programming languages, so it is safer to just avoid using it.



Figure 1-7 JIS keyboard layout

Various symbols are arranged differently than in an English keyboard (ASCII layout).

Pronunciations and notes regarding the usage of the most common symbols can be found in the table below. This table was taken from a literature reference [1] and a portion added with the consent of the authors.

Table 1-1 Symbols used in programming and their pronunciations

Symbol	Pronunciation	Notes
□	Space	Denoted as □ in the symbol column for ease of understanding. Programs use half-width spaces. Note that using full-width spaces in anything other than strings of Japanese text will result in an error that will be difficult to troubleshoot.
!	Exclamation mark	
"	Double quotes	
'	Single quotes, apostrophe	Both " and ' can be used to surround strings in Python. Either can be used, but you must use the same type of quotes on both sides of the string.
#	Pound sign, no. sign	
\$	Dollar sign	
%	Percent	
&	And, ampersand	
*	Asterisk	
+	Plus	
,	Comma	
-	Minus, hyphen	
.	Period, dot	
/	Forward slash	
:	Colon	Take note of the difference between these two
;	Semicolon	
<	Less than	
>	Greater to	
=	Equals, equal sign	
?	Question mark	
@	At sign, at	
¥\	Yen symbol Backslash	In JIS encoding, ¥ is assigned the same code as \. The Unicode (UTF-8) encoding used in Python assigns these symbols different codes, but many Windows Japanese fonts display ¥ in place of \. Mac users can simply just use a backslash.
^	Caret, free-standing circumflex	
_	Underscore, underline	In Python, you will often use underscores by combining two in a row like so: __

	Vertical bar	
~	Tilde	
[Square bracket (open bracket)	Python and many other programming languages make use of brackets and parentheses for various different uses. It can be easy to make typos.
]	Square bracket (close bracket)	
{	Curly bracket (open bracket)	
}	Curly bracket (close bracket)	
(Parenthesis (open parenthesis)	
)	Parenthesis (close parenthesis)	
<=	Less than or equal to	2 characters
>=	Greater than or equal to	2 characters
!=	Not equal to	2 characters
==	Double equal sign, equal-to operator	2 characters

Exercise 1-2 Symbols used in Programming

Review the names of the symbols used in programming as well as their locations on the keyboard.

1.8 The fundamental concepts used in programming

The following are the fundamental concepts that make up programs, both in Python and in most other programming languages.

- Arithmetic, strings, logical (true or false) operators
- Variables, variable assignment, evaluating variables (using the assigned value)
- Switching how the program functions based on various conditions (branching)
- Repeating certain lines of the program
- Coding for and calling a fixed set of operations (defining and calling functions)
- Managing complex data
- Input/output (computer terminals, GUIs, files, networks)

1.9 What part of the program do you write?

Nowadays, it is extremely rare for anybody to write an entire application all by themselves. You should understand that coding generally consists of programming things that fall in between the two categories below.

- **Framework:** The GUIs used by applications on personal computers as well as the web servers that web applications run on are almost always pre-existing programs. A program like this is called a framework.
- **Library:** On the other hand, mathematical functions like sine and cosine that many people will find useful are generally used as part of a pre-existing library.

That is to say, you code the specific operations of their program within a framework while using a

library that suits your programming needs.

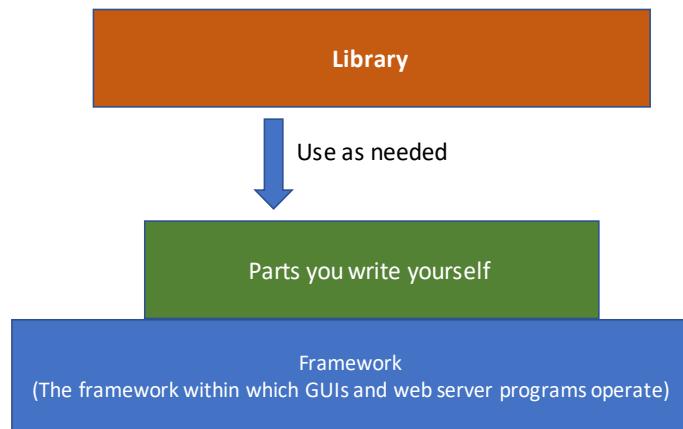


Figure 1-8 Frameworks and libraries

References

- [1] 喜多 一, 岡本雅子, 藤岡健史, 吉川直人：写経型学習による C 言語プログラミングワークブック, 共立出版 (2012, in Japanese)

2. Python: Execution Environment and How to Use It

2.1 Learning goals of this chapter

- Learn how to start Python's integrated development environment, IDLE.
- Learn how to operate the Python Shell within IDLE.
- Learn how to use the editor to edit Python programs (scripts) in IDLE.

2.2 Assumptions regarding the learning environment

This text was written with the assumption that Kyoto University's dedicated learning computers would be used. As such, it assumes Python learning will occur in the following environment.

- Operating system: Windows 11
- Python distributable: Anaconda (made with Python 3)
- Python integrated development environment: IDLE (included with Anaconda)

Learners should install Anaconda on their own PCs. In the case that you do not intend to use the numerical calculation modules introduced in Chapter 16 (NumPy, matplotlib, pandas), the original Python package will suffice.

There are various integrated development environments for Python aside from IDLE, including Jupyter Notebook and Spyder. IDLE is used as the integrated development environment for this text because its functions are limited and thus it is easier for beginners to understand (easier for instructors to teach with). In addition, it is easier to operate the turtle graphics that will be used as examples. However, you should note that its startup method and behavior is slightly different depending on whether you are using Windows or macOS. Important points regarding its use in macOS will be presented later on.

2.3 Setup

Create the folder where you will be saving the Python programs (scripts) that you write for this class. For example, you can make a folder called "Python Scripts" within your "My Documents" folder.¹.

¹ If you make a folder on the NextCloud N: drive on one of the university's computers, you will be able to access it on your own PC at home.

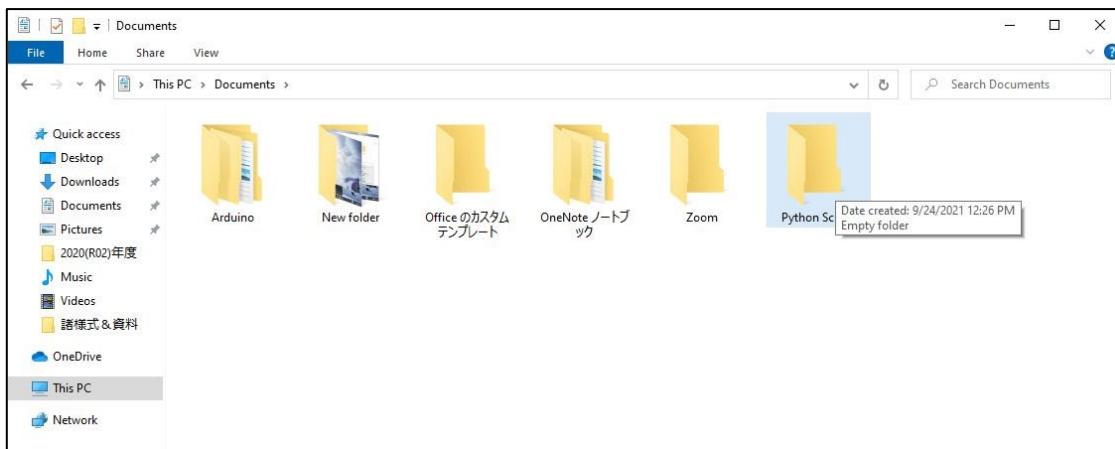


Figure 2-1 Creating a folder to hold your programs

2.4 Launching IDLE

From the start menu, select the 'Anaconda Prompt' found within the 'Anaconda3' folder and double click to start it. Once it starts, launch IDLE by typing `idle` (in uppercase or lowercase letters) into the window and pressing the ENTER key.

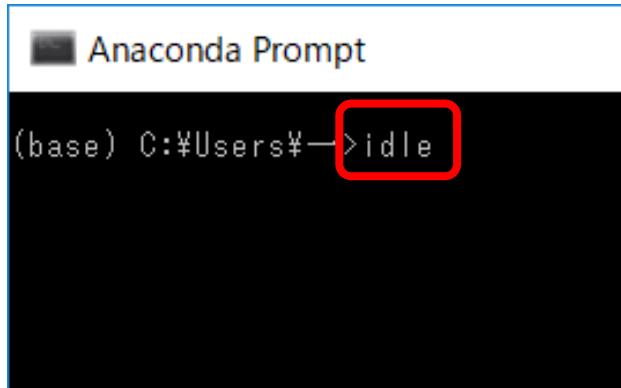


Figure 2-2 Starting IDLE from the Anaconda Prompt

2.5 Python Shell

2.5.1 Confirming that it launched

When you launch IDLE, a Python shell like the one shown in the figure below will appear. This is an environment in which Python can be executed in an interactive manner. Please check the following two things:

- **Double check the window title.** The currently running Python version (IDLE Shell 3.10.12 in this case) is displayed in the window title. When you have multiple versions of Python installed,

there are times when the incorrect version (Python 2, for example) is launched. If this happens, double check how to launch IDLE.

- **Double check the prompt.** The “>>>” within the window is a symbol (called a prompt) meant to prompt you to input commands. You can input Python commands here via the keyboard.

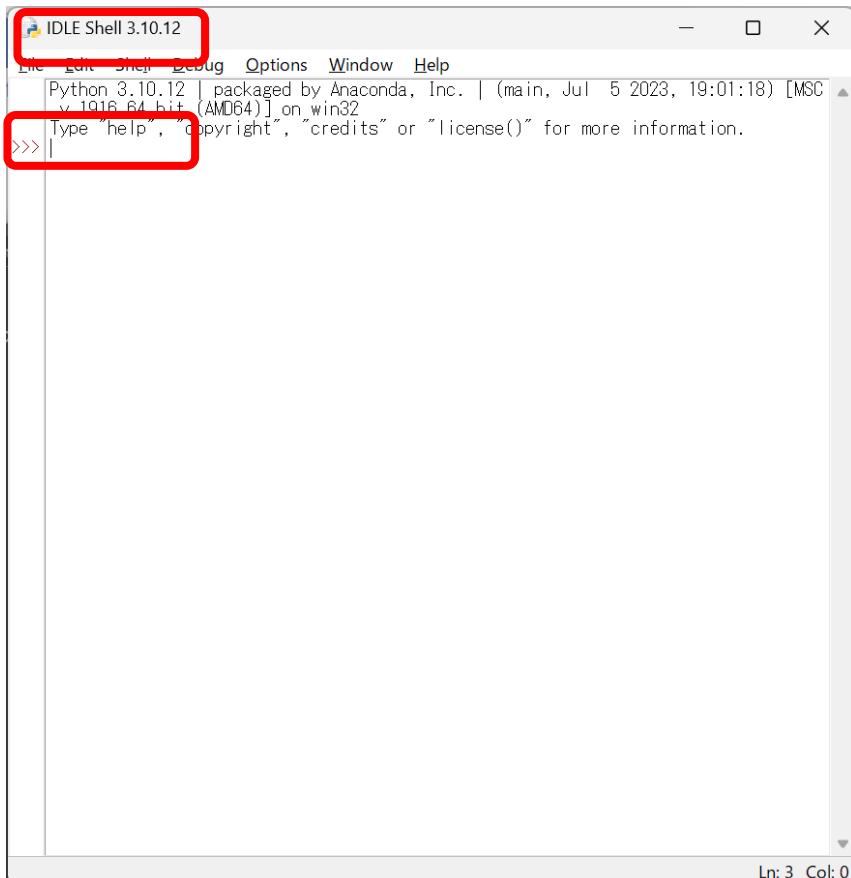


Figure 2-3 IDLE’s Python Shell

2.5.1 Executing Python commands

Input

1+2

after the prompt in the Python shell and press the ENTER key. Henceforth, **commands to be written into the prompt will be shown in red text.** This is a full-fledged Python program that gives the answer to 1+2. The shell should execute this and return

3

in response. Results returned from the prompt will be written below in blue text.

Arithmetic operations in Python can be performed as shown in the table below. Multiplication uses “*” and division uses “/.” Just like in mathematics, multiplication and division will be prioritized over addition and subtraction. In addition, you can use () in order to specify the desired computation sequence.

It is worth noting that in Python 3, “/” yields a float variable even when used on two integers. When an integer is needed, you should use “//.” Also, there are many cases in which you would need to use

the remainder of a division operation in their program. The “%” operator can be used to obtain this remainder.

Table 2-1 Arithmetic operations in Python

Operator	Operation	Notes
+	Addition	
-	Subtraction	
*	Multiplication	
/	Division	Returns a float variable in Python
//	Integer division	
%	Remainder	Gives the remainder of a division operation
**	Exponent	Note that this is 2 characters.
()	Prioritized operations	Other types of brackets cannot be used for this purpose.

Exercise 2-1 Reviewing arithmetic operations

Practice arithmetic operations in the Python Shell.

Input each of the next two lines (one at a time). Reference the figure to the right.

a = 1 + 2

a

The first line is a command that assigns the value of the equation “1+2” on the right-hand side of the “=” to the variable “a” on the left-hand side. The shell will not display anything after this command and will simply request the next input.

The second line confirms the value of the variable a.

3

should be what the shell displays. Next, try inputting

print(a)

into the prompt. print() is a function that outputs the expression within the () onto the shell as characters. As you would expect,

3

is displayed.

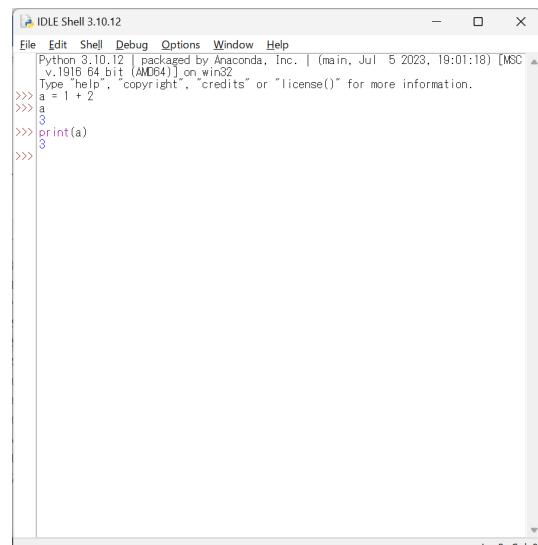


Figure 2-4 Operating the Python Shell

Simply inputting a variable's name into the Python shell will display its value. In the programs that you will code later on, which will be scripts in which multiple lines are executed all at once, will require you to explicitly use the `print()` function.

2.6 Writing and running scripts

Next, we will learn how to write a multiline Python script and execute it all at once. To do this, you will use the IDLE Editor to edit the commands.

2.6.1 Creating a new file

To create a new program, select “New File” from the “File” menu in the shell window. This should launch the IDLE Editor.

2.6.2 Verifying the IDLE editor

The IDLE Editor and the Python shell look very similar. Use the three points detailed below in order to tell them apart.

- The title of the window will be the name of the file that you're editing. If you have selected “New File,” the window title will be “Untitled.”
- The menus in this window are different than those in the Python shell. Make sure that there is a menu called “run.”
- The interior of the window is blank. There is no “>>>” prompt like in the shell.
- The line and column of the cursor should be displayed in the bottom right if you are using Windows.

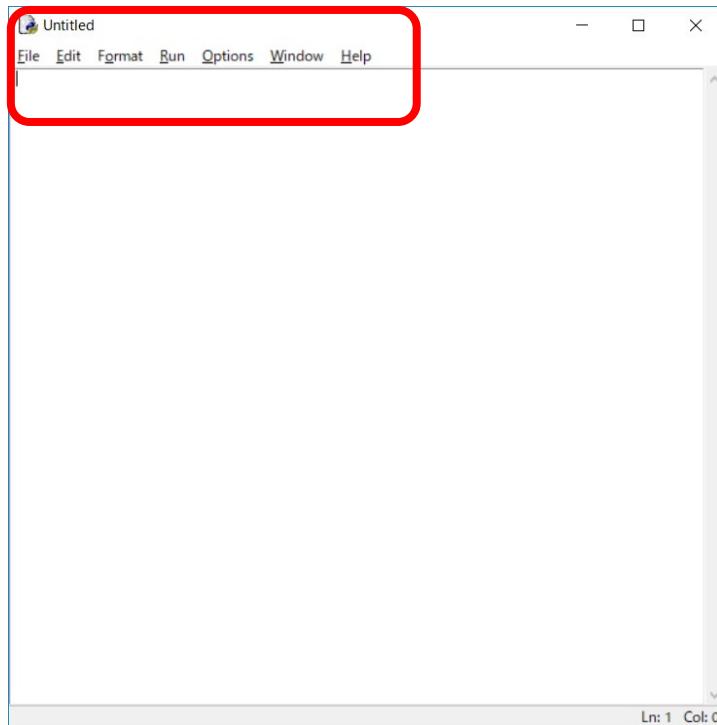


Figure 2-5 Note the differences between IDLE Editor and the Python shell

Exercise 2-2 Differences between the Python shell and IDLE Editor

Please review the differences between the Python shell and IDLE Editor.

2.6.3 Coding, saving, and running a Python program

It's only a two line program, but please input the text found in the yellow section of the table below into the IDLE Editor.

Program 2-1 (p2-1.py)

Row	Source code	Notes
1	a=1+2	Assigns the result of the equation "1+2" on the right-hand side to the variable a.
2	print(a)	Outputs the value of the variable a to the screen.

Confirm that there are no typos and then select “Run” and then “Run Module.” Run means to execute the program, and module refers to the Python program that is currently being edited.

As this is a new program, you will need to save it. Save it as p2-1.py (.py is the filename extension for Python programs) in the folder that you created for your Python programs. After doing so, it will be run in the Python shell and the results will be displayed.

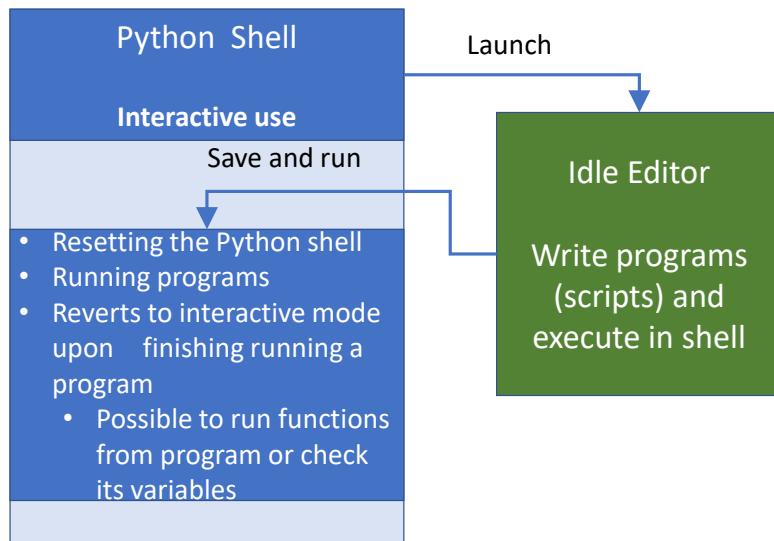


Figure 2-6 Interactions between IDLE shell and Editor

When you tell the Idle Editor to run something, the program is saved in the file, the Python shell is reset, and the program is run¹. When the program has finished running, the Python shell will revert to interactive mode where it can receive input from the keyboard. In this mode, you can check the values of the program's variables and call its functions.

Exercise 2-3 Confirmation of the result after execution of Program 2-1

Once p2-1.py has finished running, run the following command to check the value of a.

```
print(a)
```

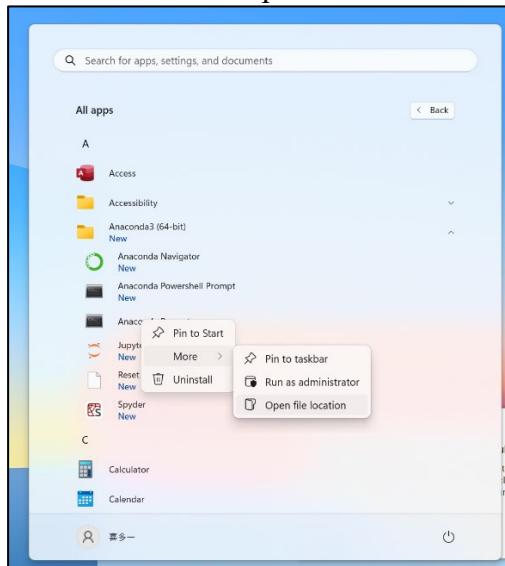
2.7 Setting the working directory with the Anaconda Prompt

We created a folder to store our Python programs, so let's set it so that this folder is opened by default. You are not able to specify a working directory in IDLE, so you will just set one in the Anaconda Prompt that runs IDLE. Set the working directory using the following procedure.

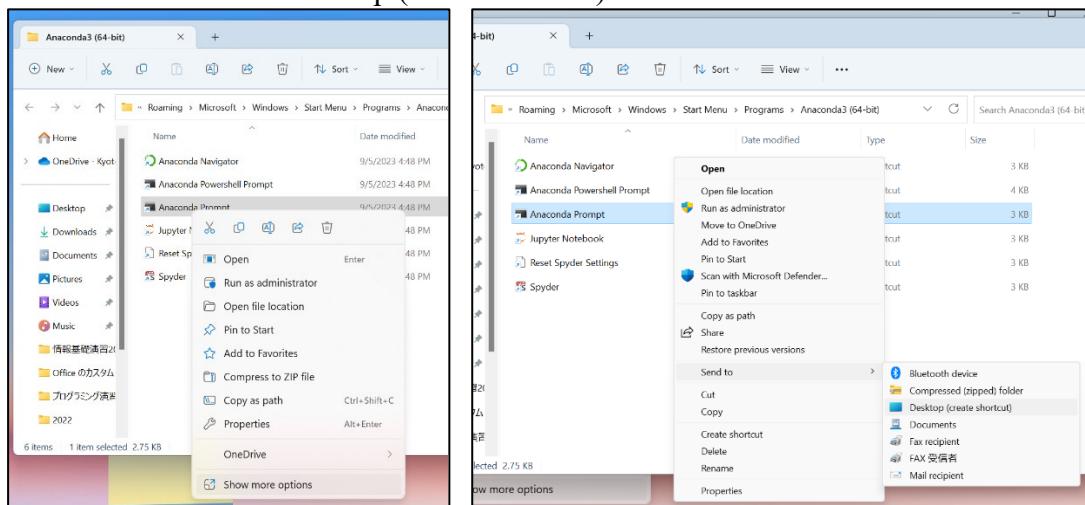
1. Create a shortcut for the Anaconda Prompt on the desktop
 - 1) Right click on the Anaconda Prompt in the Start Menu

¹The reason that the shell needs to be reset is to eliminate the potential effects of any lingering variables from when the shell was in interactive mode.

- 2) Select “More” => “Open file location”

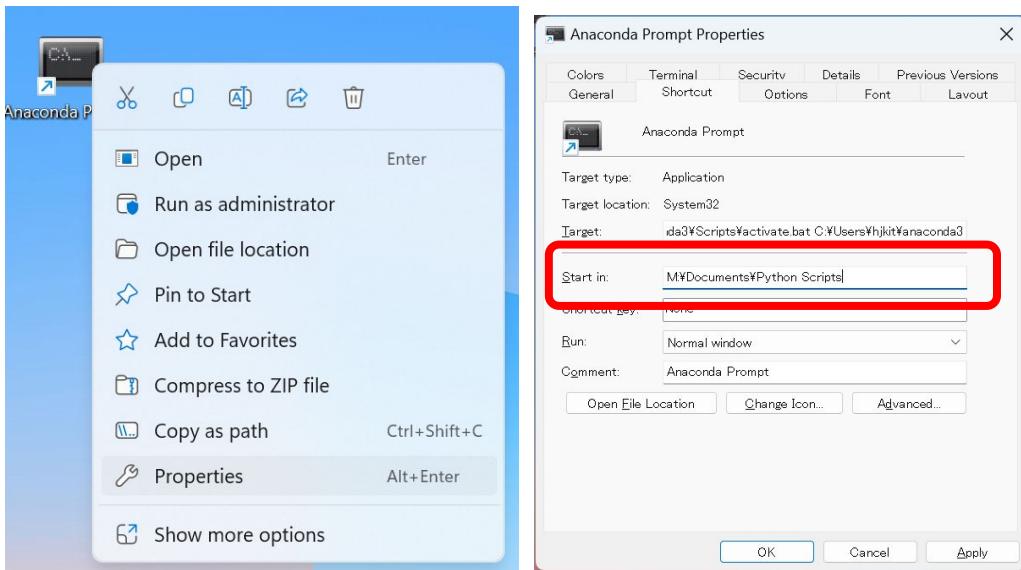


- 3) Right click on the Anaconda Prompt icon in the explorer
 4) Select “Send to” => “Desktop (create shortcut)”

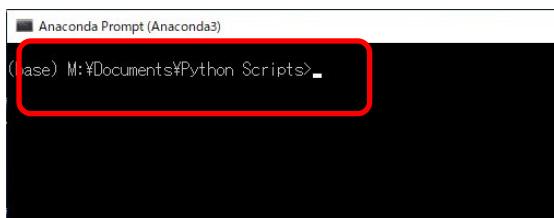


2. Set a working directory using the Anaconda Prompt shortcut on the desktop.

- 1) Right click the Anaconda Prompt icon on the desktop
- 2) Select “Properties”
- 3) Add the folder location of your Python script folder to “Start in”
- 4) Click “Ok”



From now on, when you double click this desktop icon, the Anaconda Prompt and idle will work from the specified folder.



2.8 IDLE keyboard shortcuts

IDLE's Python shell and IDLE Editor are very simple, however they come with some several useful keyboard shortcuts. These can be read in IDLE's online manual, but the most commonly used ones are listed in 18 Appendix: Useful notes on Python and IDLE.

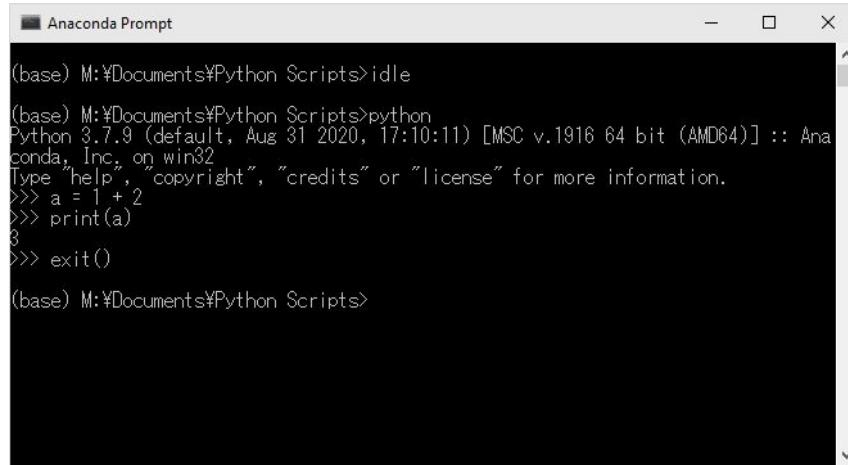
2.9 Executing Python commands

Python programs can also be run directly via the Anaconda Prompt. Please go through the following steps.

1. Close any sessions of IDLE and Anaconda Prompt that are currently open.
2. Specify the working directory as described in the previous section.
3. Launch the Anaconda Prompt from the shortcut on the Desktop.
4. Input “cd” and press the ENTER key to confirm that the working directory has been set properly.
5. Input “dir” and press the ENTER key to see a list of the files that are saved in this folder. Check to make sure that p2-1.py is listed.
6. Input “python” and confirm that the Python shell is launched in the Anaconda Prompt. For the time being, you are merely confirming that it launches, so either input “exit()” or input “C”

while holding the CTRL key to close the shell.

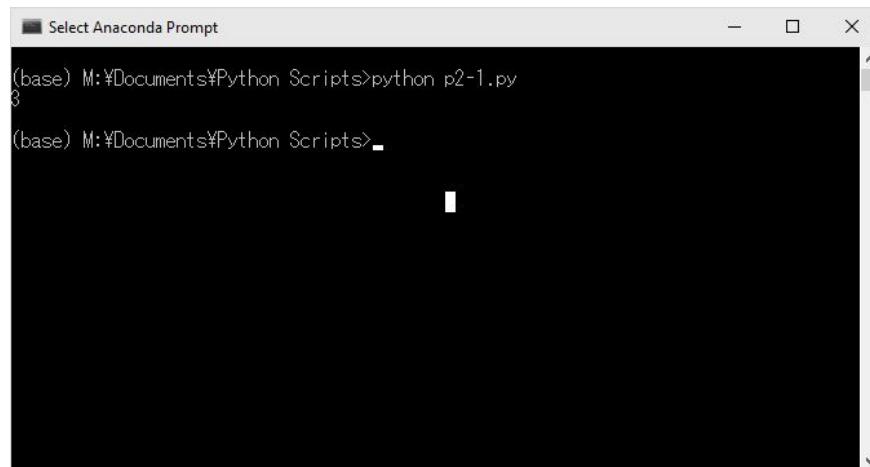
7. Specifying the name of a Python program (script) by inputting “python p2-1.py” and running the Python command will execute the program. Please confirm that this command runs as intended.
8. Specifying the -i option by inputting “python -i p2-1.py” causes it to revert to interactive mode after running the program (as it does when running the program in IDLE)



The screenshot shows a terminal window titled "Anaconda Prompt". The command "idle" is run, which starts the Python idle interface. The user then runs "python", which starts the Python interpreter. The interpreter shows the following session:

```
(base) M:\$Documents\$Python Scripts>idle
(base) M:\$Documents\$Python Scripts>python
Python 3.7.9 (default, Aug 31 2020, 17:10:11) [MSC v.1916 64 bit (AMD64)] :: Ana
conda, Inc. on win32
Type "help", "copyright", "credits" or "license" for more information.
>>> a = 1 + 2
>>> print(a)
3
>>> exit()
(base) M:\$Documents\$Python Scripts>
```

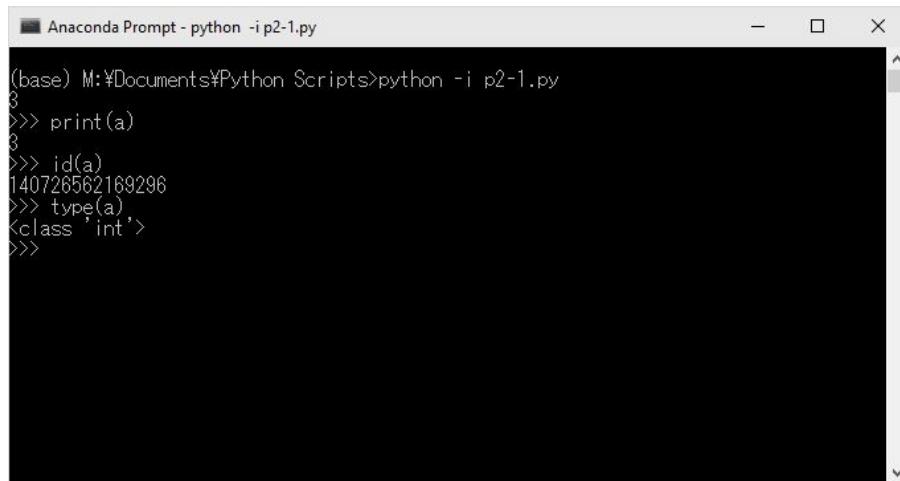
Figure 2-7 Running Python in interactive mode



The screenshot shows a terminal window titled "Select Anaconda Prompt". The command "python p2-1.py" is run, which executes the script p2-1.py. The output of the script is shown:

```
(base) M:\$Documents\$Python Scripts>python p2-1.py
3
(base) M:\$Documents\$Python Scripts>_
```

Figure 2-8 Running Python via a specified script



```
Anaconda Prompt - python -i p2-1.py
(base) M:\$Documents\$Python Scripts>python -i p2-1.py
3
>>> print(a)
3
>>> id(a)
140726562169296
>>> type(a)
<class 'int'>
>>>
```

Figure 2-9 Using the -i option to stay in interactive mode once the program is finished running

2.10 Creating a good environment for learning Python

- Python language processor: install Anaconda on your computer
- Look over the Python Language Reference
- Keep a book on Python (one that suits your learning style) on hand
- English dictionary (data confirmation, function and variable names)
- Notebook and writing utensil (PC notepad works too): write down things that spring to mind

Exercise 2-4 Prepare your own Python learning environment and report it.

Exercise 2-5 Redo today's exercise in your personal learning environment.

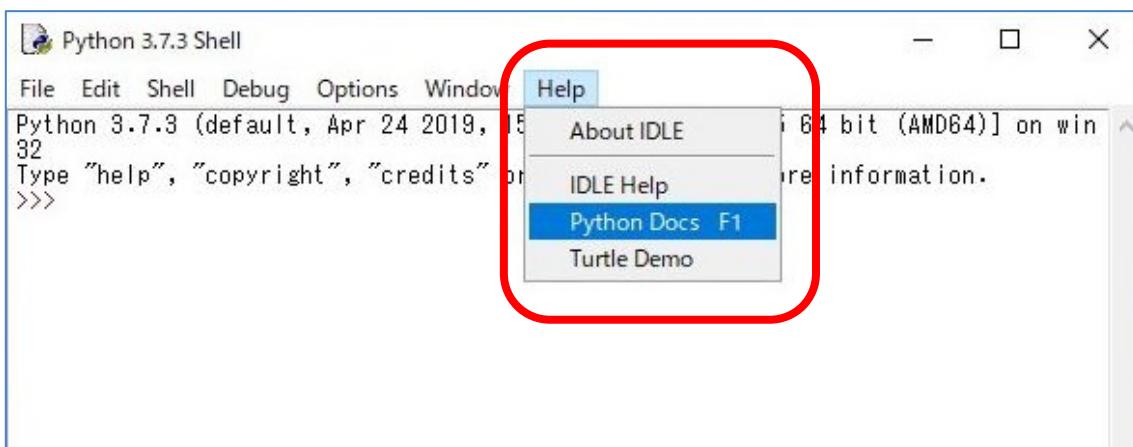


Figure 2-10 Launching the online manual from IDLE

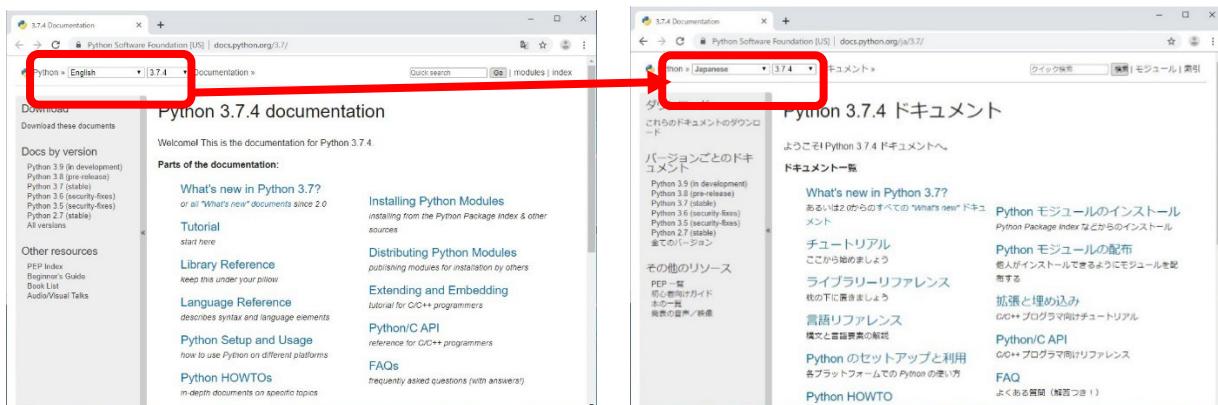


Figure 2-11 Python online manual (the right side is after selecting Japanese)

2.11 For Mac users

This text explains how to use Python in Windows. There are a few differences to consider when using it with a Mac. Please reference the list below.

2.11.1 Installing Python and launching IDLE on Mac

1) Installing Anaconda

Press the download button on the site below or scroll down the page and download the Mac OS installer from the screen that is displayed (if you don't know which to choose, select the 64-Bit Graphical Installer).

<https://www.anaconda.com/products/individual/>

Run the package file that you downloaded to install it (if you don't understand the choices in the installer, select "install for me only").

If you use a Mac equipped with the new M1 CPUs, you will be asked whether to install Rosetta, which is software that enables you to run programs designed for the older CPUs. Therefore, proceed with the installation.

Also, it is worth noting that when Anaconda is installed, the terminal environment is changed into a Conda environment more suitable for running Python (will display "(base)" at the start of every line). This is all well and good if you only plan to use the terminal for programming exercises, but it may be problematic when trying to run other software. To return the terminal to the default environment, input "conda deactivate." In order to return it to the Conda environment after deactivating it, simply input "conda activate."

If the Conda environment does not seem to be installed ("(base)" is not displayed), run the line below in the terminal, close it, and then reopen it. The "zsh" at the end is the name of the shell that runs in the terminal. In the event that a shell other than zsh is being used, simply use the name of that shell.

```
/opt/anaconda3/bin/conda init zsh
```

2) Launching IDLE

The terminal is the equivalent to the Windows command prompt. IDLE is run from the terminal.

You can launch it by selecting “Applications” => “Utilities” => “Terminal” in Finder.

Provided that Anaconda is installed, IDLE for Python 3 can be launched by inputting “idle3” using the keyboard and pressing enter (please note that this is slightly different than the previous section in which you needed to enter “idle” into the command prompt in Windows).

3) Navigating IDLE

Sometimes, when launching the IDLE Editor, you will be unable to navigate the menus by clicking. If this happens, just click on another window or the desktop background and then click back to the IDLE window (it will be titled “Python3.8”). This should fix the problem and enable you to use the menus.

4) Japanese input in IDLE

Please note that using Japanese input in IDLE can cause it to become slow and unstable. At present (9/29/2020), using Google Japanese input can lead to problems inputting characters. If this happens, it is recommended to use Mac’s standard Japanese input.

For comments and other parts that don’t affect the program’s operation, one method is to simply avoid using Japanese altogether.

5) Inputting backslashes in IDLE

In this textbook, there are sections in Chapters 11 and 12 in which yen symbols “¥” are input into the programs. Mac users should input backslashes “\”

To input the backslash symbol “\” on Mac, hold down the bottom left “option” key and press the “¥” key.



Figure 2-12 Inputting backslash on Mac

Press the ¥ key while holding the “option” key.

6) Closing IDLE

Once idle is closed, you can close the terminal window.

2.11.2 Problems with Tkinter on Mac.

Aside from the above, there are some things that rely on the operating system in which Mac users will see some differences from Windows users. Some examples include the GUI environment Tkinter, which uses a package called Tcl/Tk, and the handling of Japanese fonts in the graphing module matplotlib.

References

Many books about Python have been published in recent years, so it is likely difficult to decide which to buy. As such, we will offer a few recommendations. References [2]-[6] are introductions to Python. While it may be difficult to discern from the title, Reference [7] includes the experiences of the author, who learned Python via self-study and became a programmer. Reference [8] explains subjects that are not often included in introductory texts in the field of programming. References [9] and [10] are geared towards practical applications. References [11] and [12] are texts that discuss the numerical computing libraries, NumPy, matplotlib, and pandas, that will be touched on in this text. For books other than these ones, please confirm that they deal with Python Version 3 before using them.

- [2] Bill Lubanovic: Introducing Python: Modern Computing in Simple Package, O'reilly & Associates Inc, 2nd Ed (2019)
- [3] 柴田淳: みんなの Python 第4版, SB クリエイティブ (2017, in Japanese)
- [4] 大津真: 基礎 Python, インプレス (2016, in Japanese))
- [5] 松浦健一郎, 司ゆき: はじめての Python エンジニア入門編, 秀和システム (2019, in Japanese))
- [6] 大澤文孝: いちばんやさしい Python 入門教室, ソーテック社 (2017, in Japanese))
- [7] Cory Althoff: The Self-Taught Programmer: The Definitive Guide to Programming Professionally, Self-Taught Media (2017)
- [8] 増井敏克: 基礎からのプログラミングリテラシー, 技術評論社 (2019, in Japanese))
- [9] 日経ソフトウェア編: いろいろ作りながら学ぶ! Python 入門, 日経 BP(2019, in Japanese))
- [10] Al Sweigart: Automate the Boring Stuff with Python, 2nd Edition: Practical Programming for Total Beginners, No Starch Press, 2nd Ed. (2019)
- [11] Wes McKinney: Python for Data Analysis: Data Wrangling with Pandas, NumPy, and IPython, O'Reilly Media, 2nd Ed. (2017)
- [12] Jake VanderPlas: Python Data Science Handbook: Essential Tools for Working with Data, O'Reilly Media, (2016)

3. Assigning and Operating on Variables

3.1 Learning goals of this chapter

- Understand the flow of execution and the flow of information in Python. Learn about sequential execution.
- Learn about naming, assigning, and evaluating variables in Python.
- Learn about the basic data types in Python.
- Learn about the type() function which looks up data (object) types, and the id() function which looks up the location of an object.

3.2 Flow of execution and information in programs

3.2.1 Sequential execution

In the example from the previous chapter

```
a = 1 + 2
print(a)
```

the program is executed one line at a time starting from the top. This is called “**sequential execution**,” and it is a foundation on which programs are built. In addition, programs can:

- Diverge such that certain parts are only executed if certain conditions are met
- Repeat certain processes
- Call functions, effectively delegating the process to the definition of the function

These subjects will be tackled in later chapters. The source code of Python programs is written in accordance with what is known as “the flow of execution.”

Exercise 3-1 Programs and sheet music

Computer programs share many similarities with sheet music. A fundamental characteristic of sheet music is that the notes are played in order from the beginning (although they are read from left to right which differs from top to bottom in programs). Also, note that there is notation that enables you to change how certain parts are played or repeat certain parts.

The image shows a musical score for a piece titled "Kotonoha no Uta" (Kotonoha no Uta). The score is in 4/4 time and uses a treble clef. The lyrics are written below the notes in Japanese. There are two sets of lyrics: "(一)コ コ ノヘ ニ ハ ナ ゾニ ホヘル センネン ノ ミ" and "(二)み ど りふ く く す のは かぜに ときのか ね つ". Above the music, the instruction "稍々荘重に" (Slightly庄重ly) is written. To the right of the score, the names "水梨弥久" (Kōki Mizushima) and "下總院一" (Ichiyū Shitōin) are listed, along with the words "作詞" (Composition) and "作曲" (Arrangement). A "Sound" button with a play icon is located in the top right corner of the score area.

Sample sheet music: Kyoto University school anthem (taken from the link below)

<https://www.kyoto-u.ac.jp/ja/about/operation/symbol/song-a.html>

3.2.2 Flow of information through variables

Meanwhile, in programs, information is processed at each step in the form of numbers or strings that have been assigned to variables. As such, when compared to the flow of execution, the flow of information can be quite difficult to follow, despite occurring through the assigning and checking of the same variables. For example, in the code above, the value of the variable `a` that was set in the first line is used by the `print` function in line 2.

How about in the following example?

```
a = 1 + 2  
a = 3 + 4  
print(a)
```

In this program, the value assigned to '`a`' in line 1 is immediately overwritten in line 2. As such, you can immediately see that this assignment is meaningless for `print(a)` in the third line by simply following what happens to '`a`'.

3.3 Variable naming

3.3.1 Programs also use variable names with multiple characters

The variable name used in the previous example was '`a`'. In mathematics, letters of the alphabet (and even Greek letters) are often used. However, programming languages, which handle various types of data, can use longer variable names. For example,

```
a  
x  
x2  
root  
square_root
```

and so on.

3.3.2 Variable naming rules

Please learn the following rules.

- You can use only uppercase letters, lowercase letters, numbers, and underscores.
- Uppercase and lowercase letters are treated as different characters.

- A number cannot be used as the first character in a name.
- Reserved keywords used in Python syntax (words such as “if;” reserved keywords will be displayed in red when using the IDLE Editor) cannot be used.

Variable names can use Japanese (kanji, etc.), however this is not common practice.

3.3.3 Use variable names that are easy to understand

1) Taking mathematics as an example

Using appropriate names facilitates smoother thinking and communication. For example, in mathematics, if you write a linear function as

$$y = ax + b$$

you can immediately understand that y is a linear function of x , the slope is a , and the intercept is b . This is because it is the standard convention to use x and y as variables, to have y be a function of x , and to use a and b as parameters.

However,

$$b = xa + y$$

is the same equation that merely switches x and y with a and b . Suddenly it becomes much more difficult to understand.

2) How to name variables in Python programs

In programs, good variable naming can go a long way towards making a program easier to understand. Please try to keep the following things in mind.

- Try to choose variable names that represent what the variable does within the program.¹
- Variables with very short names (like one-character names) should only be used when they are only needed to have a very small scope to bring about their desired effect. In particular, l, o, and O (lowercase L, lowercase O, and uppercase O) can be confused for the numbers 1 and 0, so it is best to avoid using them.
- In general, use lowercase letters instead of uppercase letters. Uppercase letters are generally used for constants that do not change in value.
- Variable names with multiple words should use an underscore (_) as spaces. For example, “street_name”²
- Use English when possible. There are times where programs grow much larger than initially expected and come to be used by a large number of people. Often times this can mean people

¹ We don't often encounter the concept of “naming” in everyday life; naming kids or pets are generally the only times we name anything. However, when using computers, the act of naming things is critically important when it comes to filenames, folder names, and the like. Naming is one of the most common concepts within programming. It would be best to go in understanding that good naming sense is needed when programming.

² Alternatively, it is common to merely capitalize the first letter in each word after the first. In this case, the example would become “StreetName.”

all around the world will be using the program, so it is best to use English naming from the beginning.¹

Even beyond variable names, no matter how you write your programs, making them easy to understand is of critical importance. PEP8[13] is the recommended coding guideline for Python programs.

Exercise 3-2 Practice using various variable names

Run the program shown in Program 2-1 via the shell and practice changing the variable names to various things.

- Please note that you need to change the variable in both the first and second lines to the same thing.
- Try using a variable name of multiple words connected by an underscore.
- Also, see what error messages result from using variable names with reserved keywords or names starting with a number.

3.4 Variable assignment and evaluation

Run the following program using the Python shell.

```
a = 1  
print(a)  
a = a + 1  
print(a)
```

The variable 'a' is assigned the value of 1 in the first line.

In the third line, 'a' appears on both the left and right hand sides of the equation, so be careful when reading it. In Python, this program does the following:

1. First, the expression on the right-hand side ($a + 1$) of the assignment operator ($=$) is calculated.
 - The variable 'a' is already assigned the value of 1, so the right-hand side will use "the result of evaluating the value of a," which is one. This gives us $1 + 1$, yielding 2 as the result of the calculation.
2. Next, this result is assigned (overwritten) to 'a,' the variable on the left-hand side.

Variables can be thought of as boxes with names.

¹ There was a situation in which a FORTRAN program written by a German professor for his research was rewritten in C. Older FORTRAN specifications placed limits on variable name length, so the variables were named using abbreviated German which was completely unintelligible. The professor's program had thorough English comments accompanying it, so it was still able to fulfill its purpose.

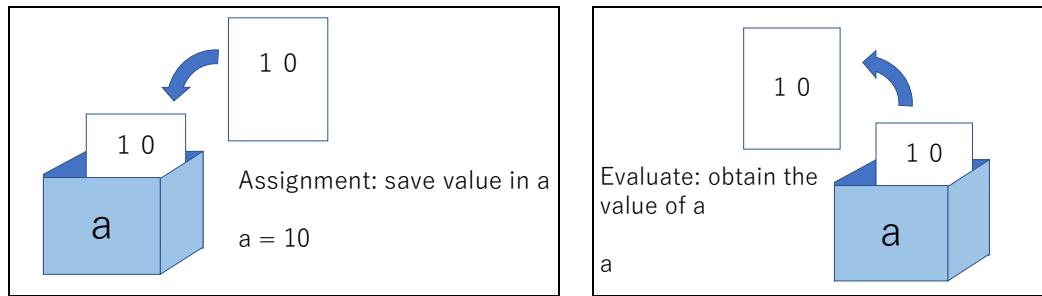


Figure 3-1 Visual representation of variable assignment and evaluation

Exercise 3-3 Explaining the behavior of variables

Below is a program that calculates the price of a ¥1000 product at 15% off.

- This program contains a single error which causes it to yield an error message when run. Please locate and explain the error.
- After correcting the error, explain how the program behaves.

```
kakaku = 1000
nebikiritsu= 15
kakaku = Kakaku*(100-nebikiritsu)/100
print(kakaku)
```

3.5 Assignment operators

In programs, you frequently need to add or subtract a fixed number (for example, 1) to a variable. You can make use of the operators below (beyond just the assignment operator “=”) in order to perform such operations more conveniently.

Table 3-1 Python assignment operators

Operator	Example	Meaning
<code>+=</code>	<code>a += b</code>	<code>a = a + b</code>
<code>-=</code>	<code>a -= b</code>	<code>a = a - b</code>
<code>*=</code>	<code>a *= b</code>	<code>a = a*b</code>
<code>/=</code>	<code>a /= b</code>	<code>a = a/b</code>

Note that the “`++`” and “`--`” operators commonly used in the C language are not present in Python.

3.6 Data types used in Python

The previous examples dealt with integers. Python programs can make use of many other data types (seen in the table below), including floating-point numbers, which contain numbers after a decimal point, strings, and Booleans (True and False). One feature of Python is that integers are not limited to a certain number of digits (although at some point they are limited by computer memory and calculation speed). For example,

`2**200`

evaluates to

`1606938044258990275541962092341162602522202993782792835301376`

As for numerical data types, complex numbers can also be used.

Table 3-2 Data types used in Python

Type Function used to convert	Explanation	Constant (literal) notation example	Notes
Integer <code>int()</code>		12345	No digit limit in Python
Floating-Point Numbers <code>float()</code>	A number that has values after the decimal point	1.0 2.99792458E8	Has a size limit (of significant digits and the range that can be expressed). E8 means $\times 10^8$.
String <code>str()</code>	A sequence of characters	'aaa' "日本語"	Strings are surrounded by single or double quotes
Boolean <code>bool()</code> ¹	Used to evaluate conditions	True False	The first letters of constants are uppercase.

¹ Named after George Boole, the man who pioneered the theory behind the algebra of logical operators.

It is worth noting that in Python, as with most programming languages, arithmetic using floating-point numbers is carried out in binary. We often express fractions using decimals, but just like how $1/3$ cannot be perfectly expressed as a decimal, $1/10$ cannot be perfectly expressed using floating-point numbers. For a more detailed explanation, please refer column chapter “What Does Float Mean?”

Exercise 3-4 Confirmation of data type

Run the following in the Python shell.

```
a = 1
b = 1/2
c = "ABC"
print(a)
print(b)
print(c)
print(type(a))
print(type(b))
print(type(c))
```

Although data (generally referred to as “objects”) has various “types” in Python, variables can be assigned values regardless of the type of data they already contain.

The `type()` function can be used to find out what type of object is currently assigned to a variable.

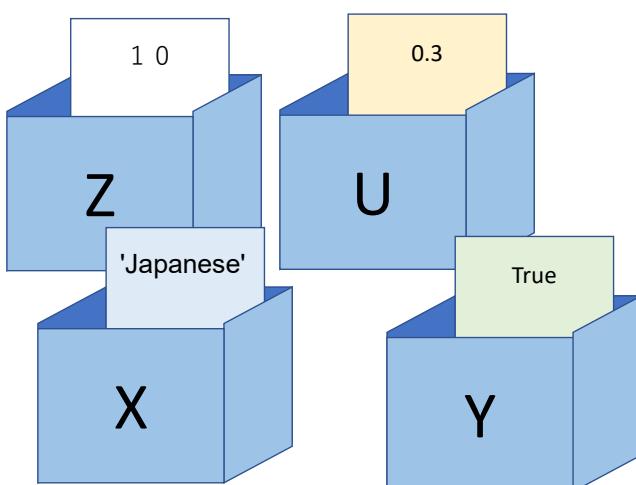


Figure 3-2 In Python, a variable can have any type

3.7 A more accurate understanding of Python variables

In reality, variables in Python do not directly hold data (objects) themselves, rather they contain information (a reference) that points to the whereabouts of the object. You do not need to worry about this very much right now, however it will become important down the line when learning about how complex data like lists are handled.

The information that points to data locations that are held by a variable can be looked up using the `id()` function.

```
a = 1
b = 2
print(id(a), id(b))
```

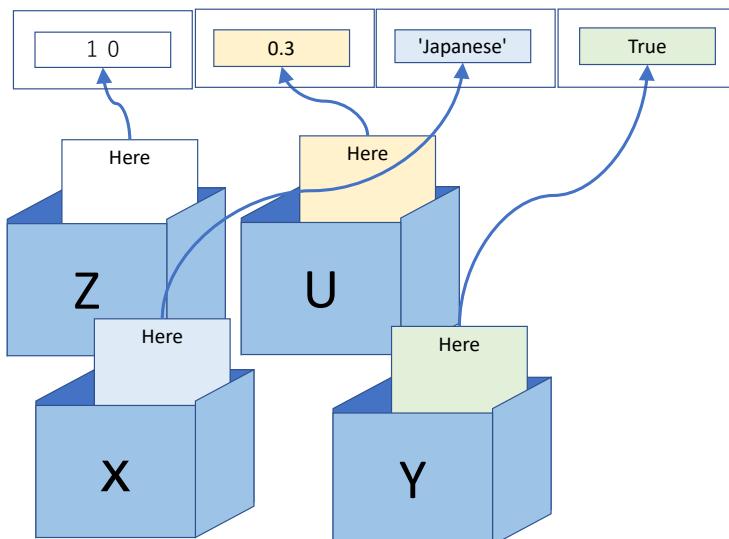


Figure 3-3 Python variables contain information on data (object) location

3.8 Assigning multiple variables

In Python, multiple variables can be assigned in one line by separating variables and expressions with “,” on both the left and right sides of the equation.¹

```
a = 1
b = 2
c, d = a*2, b*2
print(c, d)
```

Running this gives

¹ Although this is not explained here, a data type called a tuple is being used here behind the scenes.

2 4

as the output.

In order to switch the values of two variables, most programming languages assign the value to a temporary variable (tmp in the example below) as shown below.

```
a = 1  
b = 2  
tmp = a  
a = b  
b = tmp
```

In Python, this can be done in the following manner.

```
a = 1  
b = 2  
a, b = b, a
```

References

- [13] PEP 8 -- Style Guide for Python Code, <https://www.python.org/dev/peps/pep-0008/> (Accessed on 2/12/20)

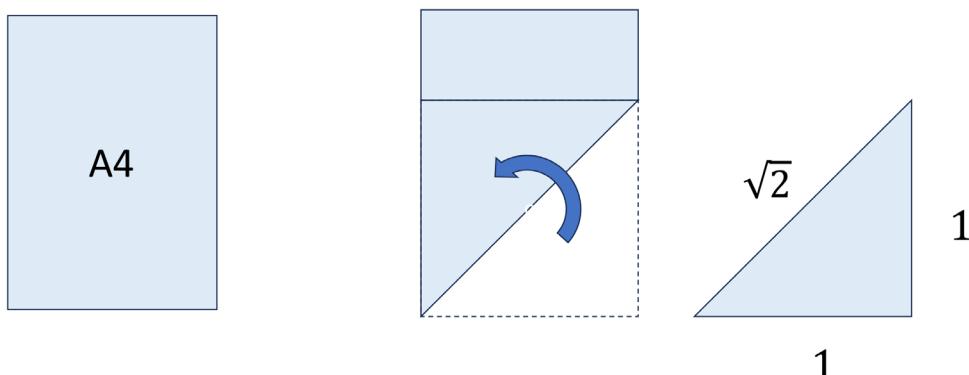
4. Exercise: Find the Square Root

4.1 Learning goals of this chapter

- For this exercise, we will deal with sequential execution and handle variables in order to find an **approximation for the square root** of a given number. While the calculation method introduced in this chapter is quite simple, it requires division of numbers with many digits. As such, it is difficult to perform by hand, but computers can carry it out with ease.

4.2 The square root hiding in plain sight

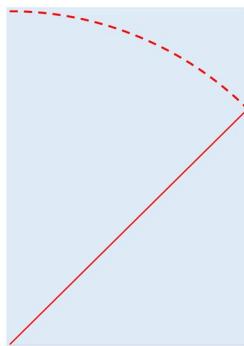
This textbook is designed to be able to be printed on A4 paper. Take a sheet of A4 paper and fold the bottom right corner so it overlaps with the left side . The triangle that results from this is an isosceles right triangle.



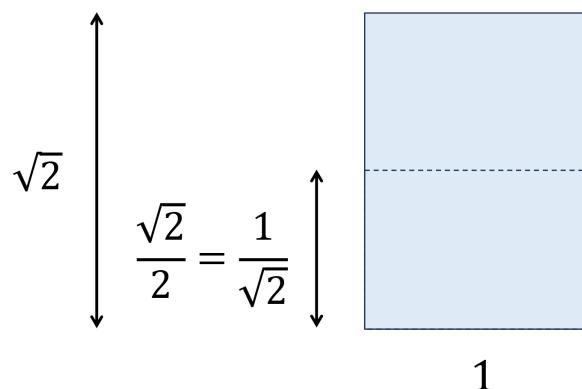
For simplicity's sake, think of the two equivalent sides of this triangle as having a length of 1 (for those who dislike that this differs from the actual length, think of the small side of the A4 paper as 210mm), then we get that the length of the hypotenuse x is equal to

$$x^2 = 1^2 + 1^2 = 2$$

according to the Pythagorean theorem. Thus, x has a value equal to the square root of 2 ($\sqrt{2}$), or about 1.414. As a matter of fact, this length is the same as the length of the long side of the paper as seen in the figure below.



When folding A-series paper in two, the area is halved but the shape does not change. Setting the horizontal side's length as 1 and the vertical side's length as $\sqrt{2}$, when one folds it in two the vertical side's length becomes $\sqrt{2}/2 = 1/\sqrt{2}$ and the horizontal edge's length becomes $\sqrt{2}$ times the length of the vertical edge resulting in the shape remaining unchanged.



In reality, A4 paper is 210 mm x 297 mm¹, so the ratio of the vertical side to the horizontal side is 297/210 which is approximately equal to $1.414 \cong \sqrt{2}$. **The square root of two is hiding in plain sight all around us.**

However, **the square root is defined as the number that, when multiplied with itself, produces the desired number. It is not apparent how one should find this value.** Many students are told that $\sqrt{2}$ or perhaps $\sqrt{3}$ and $\sqrt{5}$ are used often so they need to be memorized. It kind of leaves a bad taste in one's mouth, right?

Let's use programming to solve for an approximate square root.

4.3 Calculation procedure

In order to solve for the square root $\sqrt{2}$ of a given number, follow the procedure below.

- Let the approximation of the square root be r . It can be initialized to the number whose square root you want to find (2 in this example), or it can even be set to 1. In this case, let $r = 2$.
- As another approximation of the square root, divide the number whose square root you wish to find by the approximation r . In this example, that would give $2/r = 2/2 = 1$. If the

¹ A0 paper is 841 mm x 1189 mm, so four times the size of A4 paper on each side. This is because at those dimensions the area becomes 841 mm x 1189 mm = 1,007,518 mm² which is approximately 1 square meter.

approximation r is indeed the square root being solved for, $2/r$ will become the square root as well.

- The new approximation r^{NEW} is the midpoint (average) between these two values. In this example, that would be:

$$r^{\text{NEW}} = \frac{r + \frac{2}{r}}{2} = \frac{2 + \frac{2}{2}}{2} = \frac{2 + 1}{2} = 1.5$$

- At this point, simply repeat the process after setting the value of r to r^{NEW} .

$$r^{\text{NEW}} = \frac{1.5 + \frac{2}{1.5}}{2} = \frac{1.5 + 1.33333}{2} = 1.41666$$

As you can see, the number is indeed approaching the square root of 2. Repeating this procedure over and over will further increase the accuracy of the approximation.

Laying out all of the variables in order to make this into a program yields the following:

- Assign the number (>0) whose square root is being approximated to the variable x .

$$x = 2$$

- Set an initial value (>0) for the square root approximation and assign this to the variable r_{new} . In this example, we will set this value equal to x .

$$r_{\text{new}} = x$$

- Assign the value of r_{new} to the variable r_1 .

$$r_1 = r_{\text{new}}$$

- You can think of another approximation, x/r_1 , and assign this value to the variable r_2 ($r_2 = x/r_1$).

$$r_2 = x/r_1$$

If r_1 is the square root of x , r_2 will also become the square root of x . If it isn't, one will be higher than the true value, and one will be lower, making the true value fall somewhere in between.

- As such, the new approximation can be set to the average of r_1 and r_2 , $(r_1 + r_2)/2$, and update the variable r_{new} by assigning it this new value.

$$r_{\text{new}} = (r_1 + r_2)/2$$

- Repeat steps 3-5 a certain number of times.

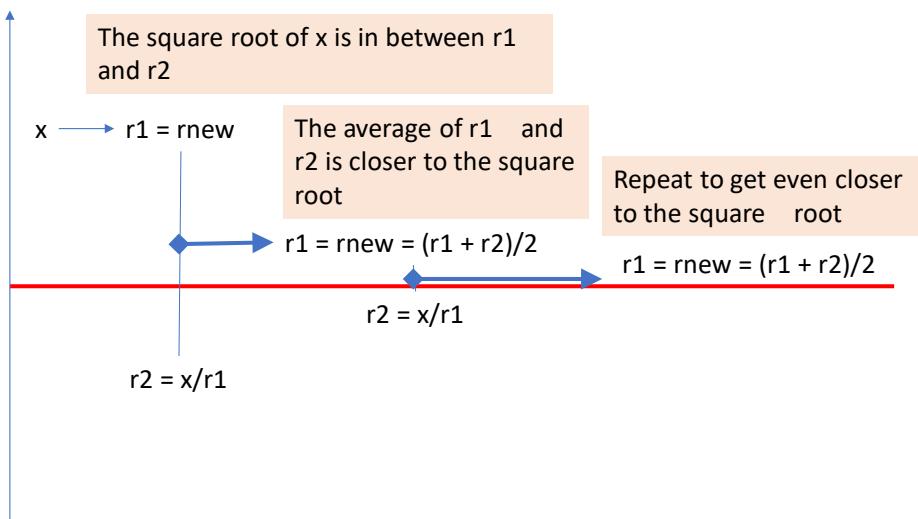


Figure 4-1 Intuitive explanation of square root approximation

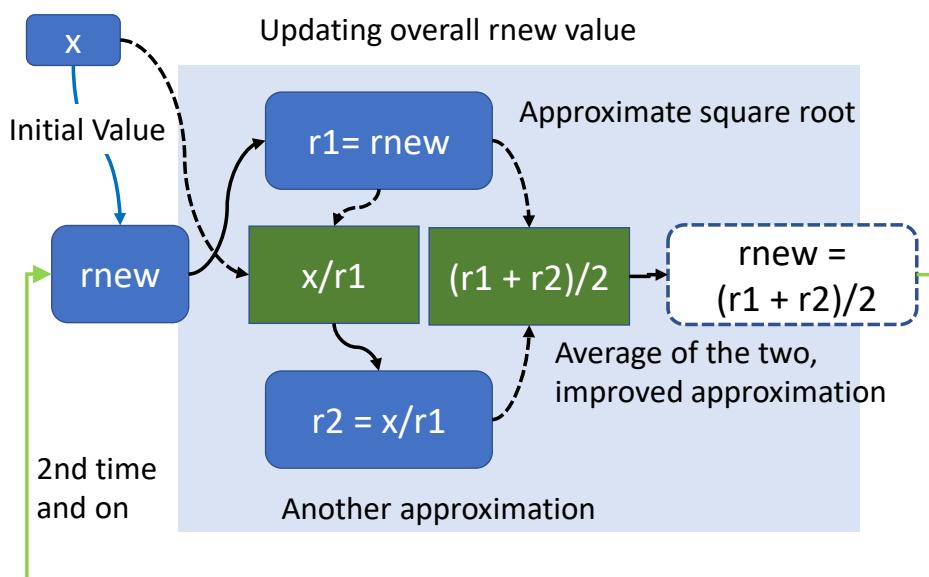


Figure 4-2 Calculation steps

4.4 Python program

Exercise 4-1 Creation and execution of a program to obtain square root

Input the source code of Program 4-1 from the following table into the IDLE Editor, save it as p4-1.py, and run it. (Use ‘space’ instead of ‘_’)

Program 4-1 Program that solves for square roots (ver. 1, p4-1.py)

Row	Source code	Notes
1	#Find_the_square_root_of_x	
2	x=2	Lines starting with # are comments
3	#	
4	rnew=x	
5	#	Initial assumption for the approximation
6	r1=rnew	
7	r2=x/r1	
8	rnew=(r1+r2)/2	
9	print(r1,rnew,r2)	
10	#	
11	r1=rnew	The code below this section simply repeats the red portion 3 times.
12	r2=x/r1	
13	rnew=(r1+r2)/2	
14	print(r1,rnew,r2)	
15	#	
16	r1=rnew	
17	r2=x/r1	
18	rnew=(r1+r2)/2	
19	print(r1,rnew,r2)	
20	#	
21	r1=rnew	
22	r2=x/r1	
23	rnew=(r1+r2)/2	
24	print(r1,rnew,r2)	

If you obtain the following result, the program ran as expected.

```
2 1.5 1.0
1.5 1.4166666666666665 1.3333333333333333
1.4166666666666665 1.4142156862745097 1.411764705882353
1.4142156862745097 1.4142135623746899 1.41421143847487
```

With 4 repetitions, you will obtain the result of 1.4142135623746899.

If you calculate the root by using

$2^{**}(1/2)$

you will get

1.4142135623730951

Note that the result of the program is accurate to the 11th digit after the decimal point.

An intuitive explanation of this approximation method is given above, however this is simply an application of what is known as Newton's method to solving for square roots. For more details, reference the column titled "Newton's Method."

Exercise 4-2 Experience errors (1)

Try a mistake of spelling "rmew" instead of "rnew" in line 4 of Program 4-1, and examine what will happen if you run the program. See also "19 Appendix: How to Read Error Messages in IDLE/Python."

Exercise 4-3 Solve for the square root of some other numbers.

1. Alter p4-1.py to solve for the square roots of other positive numbers.
2. Also, try and see what happens when this program attempts to solve for the square root of 0. Don't just look at the error message, actually go through the program step-by-step (called tracing) to see where the problem occurs.

4.5 Be careful when using division

In programs, you will frequently run into situations where a variable is used as a divisor. Among the four basic arithmetic operations, division has the unique feature in which it cannot work if 0 is used as the divisor. When programming, be constantly mindful of whether or not the divisor in a division problem will be 0.

4.6 Notation to make equations easy to read

From the 8th line of p3-1.py, the equation

$$\text{rnew} = (\text{r1} + \text{r2})/2$$

uses the assignment operator (=), addition (+), division (/), and () which determine operation priority.

- Note that **spaces are placed before and after = and +** in order to make the equation easier to read.
- On the other hand, spaces are not placed directly within the () or on either side of the /. Removing all of the spaces yields

$$\text{rnew}=(\text{r1+r2})/2$$

which looks pretty cramped and is difficult to read.

- A general principle to follow would be to forego spaces before and after high priority operations like * and /, while adding spaces before and after low priority operation like +, -, and =.

5. Lists

5.1 Learning goals of this chapter

Until now, we've dealt with simple numbers and simple strings. In Python, there are multiple ways to handle batches of data all at once. Lists are one of these methods. In this chapter, you will learn the following things about using lists in Python.

1. What is a list?
2. How is a list created?
3. Learn how to access the elements of a list.
4. Learn about assigning and copying lists
5. Learn the basics about tuples and dictionaries, which are alternative ways to handle a bunch of data all at once.

5.2 Learning with the Python shell

This chapter is going to have a lot of short code. Rather than inputting it into the editor and running it, you can learn more efficiently by inputting it into the Python shell and seeing what it does.

- Because the Python shell processes code line-by-line, you cannot just copy and paste multiple lines into the shell and run them. Instead, input code one line at a time.

In order to limit the number of pages in this text, **input will be printed in red font** and **output will be printed in blue font** below. Although the Python shell prompt is omitted, please proceed by inputting the red text and confirming that it results in the outputted blue text.

5.3 What is a list?

In everyday life, if you mention a “shopping list,” this refers to a short memo containing a list of items you intend to buy. In a similar manner, a Python list is a way for multiple pieces of data to be handled all at once. By ascribing multiple pieces of data, a set order, you are able to handle them as a single entity. For example, inputting

```
a = [5, 1, 3, 4]
```

and then

```
print(a)
```

prints the entire list.

```
[5, 1, 3, 4]
```

Inputting

```
print(a[0])
```

prints the element of the list at index zero.

5

Inputting

```
print(a[2])
```

prints the third element of the list.

3

5.4 Generating lists

5.4.1 Generation by specifying elements

Lists are generated by enclosing the elements within [] and separating them using “,” like this:

```
a = [5, 1, 3, 4]
```

Or this:

```
b = ['Sanjyo', 'Shijyo', 'Gojyo', 'Shichijyo']
```

As you can see, strings can be used as elements of a list. Also, variables and equations can be included as elements of a list.

```
c = 5
```

```
a = [c, 1, 3, 4]
```

a

[5, 1, 3, 4]

A long list of the same elements can be made by multiplication of list and an integer:

```
a = [1]*4
```

a

[1, 1, 1, 1]

However, it should be noted that if the element in the list is a complex objects like a list, multiplication makes not make a list of copies of the element but just a list of the identical elements.

5.4.2 Combining with the range() function

An empty list can be generated as an object of the list class like so:

```
e = list()
```

You can combine this with the range() function, which generates a series of numbers, like so:

```
n = list(range(5))
```

Printing this list using

```
print(n)
```

will show a list of numbers from 0 to 4.

```
[0, 1, 2, 3, 4]
```

5.4.3 Generating lists from strings

It is possible to generate lists using strings instead of the range() function. Inputting

```
s = list('abcde')
```

and then

```
print(s)
```

Printing this list using

```
['a', 'b', 'c', 'd', 'e']
```

As you can see, you get a list containing the string ‘abcde’ split up into individual letters.

The string class contains a method called split() which can split a string into smaller segments using a specified character to delimit the breaks¹. For example, inputting

```
t = "a textbook of Python"
tlist = t.split()
```

Printing this list using

```
print(tlist)
```

yields

```
['a', 'textbook', 'of', 'Python']
```

which is a word list generated by using spaces as the delimiter.

5.5 Methods

In the previous example, we used the split() method to split a string using spaces as the delimiter. Data handled by Python are generally referred to as “objects,” and the ways you can operate on this data is determined in advance, and they change based on the class, type, and value of the data. These predetermined operations are called “methods,” and can be called by placing a period after the variable name and then writing the name of the method. In the previous example, the split() method was called by placing a period after the variable t and then including “split()” after the period.

```
t = "a textbook of Python"
tlist = t.split()
```

¹ Calling this method without an argument will cause it to default to using spaces as the delimiter. You can specify a desired delimiter. You can also input help(str.split) into the Python shell to get an explanation of this method.

A method can also be called by attaching it to the string itself. For the example above, this would become:

```
tlist = "a Python textbook".split()
```

A few methods for lists will be introduced below, so be sure to remember what a method is and how to call one.¹

5.6 Accessing elements in a list

Elements of a list can be accessed by including the element's index within [].

```
a = [5, 1, 3, 4]
print(a[0])
```

yields

5

Then, by inputting

```
a[1] = 2
print(a)
```

2 is assigned to the second slot (index 1) of a, yielding

[5, 2, 3, 4]

The length of a list can be obtained using the len() function.

```
print(len(a))
```

yields

4

Please note that this is a function, not a method that can be called by “a.len()”

5.7 Negative indices and slicing

Python allows for list indices to be described in a wide variety of ways.

5.7.1 Negative indices

Using an index of -x (x being an integer) refers to the element whose index is x elements from the end of the list.

¹ Methods are very similar to functions, which will be introduced in a later chapter. The major difference is that functions *are not* tied to specific objects, while methods *are* mainly restricted to operating on certain objects. The way to call them is also similar. Classes exist as a way for programmers to set their own data types that include their own method definitions. These will also be introduced in a later chapter.

```
a = [5, 1, 3, 4]
print(a[-1])
```

yields the last element

4

See the table below for reference.

	a[5,	1,	3,	4]	
Accessing using a positive index	a[0]	a[1]	a[2]	a[3]	
Accessing using a negative index	a[-4]	a[-3]	a[-2]	a[-1]	

5.7.2 Slicing

By making the index [starting index:stopping index], you can take out a select part of a list. This is called a **slice** of the list. Please keep in mind that this includes **up to the index before the stopping index**.

```
a = [5, 1, 3 4]
b = a[1:3]
print(b)
```

yields

[1, 3]

5.8 Adding to and combining lists

Lists come with various predetermined methods¹. In this section, we will introduce the `append()` method, which adds elements to a list, and the `extend()` method, which combines multiple lists together.

5.8.1 append method

This method adds the arguments to the end of a list.

```
a = [5, 1, 3 4]
a.append(2)
print(a)
```

This adds 2 to the end of list a, resulting in

[5, 1, 3, 4, 2]

¹ Inputting “`help(list)`” into the Python shell will enable you to read an explanation on the methods available for lists.

5.8.2 extend method

The `extend()` method is used to combine two lists.

```
a = [5, 1, 3, 4]
b = [2, 6]
a.extend(b)
print(a)
```

This will add list b to the end of list a, resulting in the following output:

```
[5, 1, 3, 4, 2, 6]
```

Note: using the `append` method will append the entirety of list b as the final element of list a, as seen in the example below.

```
a = [5, 1, 3, 4]
b = [2, 6]
a.append(b)
print(a)
```

The entirety of list b is appended as the final element of list a, leading to the following output:

```
[5, 1, 3, 4, [2, 6]]
```

5.9 List assignment and duplication

First, try running the following program:

```
a = [1, 2, 3]
b = a
print(a)
print(b)
```

This should result in the following output:

```
[1, 2, 3]
[1, 2, 3]
```

Next, try to predict what the result will be from running a program like the one below.

```
b[0] = 0
a[1] = 0
print(a)
print(b)
```

This does not result in

```
[1, 0, 3]
```

```
[0, 2, 3]
```

but rather

```
[0, 0, 3]
```

```
[0, 0, 3]
```

This is because variables a and b refer to the exact same list. Checking this by inputting

```
print(id(a), id(b))
```

reveals that a and b both have the exact same id (which will vary based on your operating environment).

In Python, the variables themselves do not contain the data, but rather the location of the data. Thus,

```
b = a
```

does not assign the data that a represents to b. Rather, it assigns to b the location of the data (list) represented by a. As such, any changes to the elements of either a or b are in fact changes made to the same list.

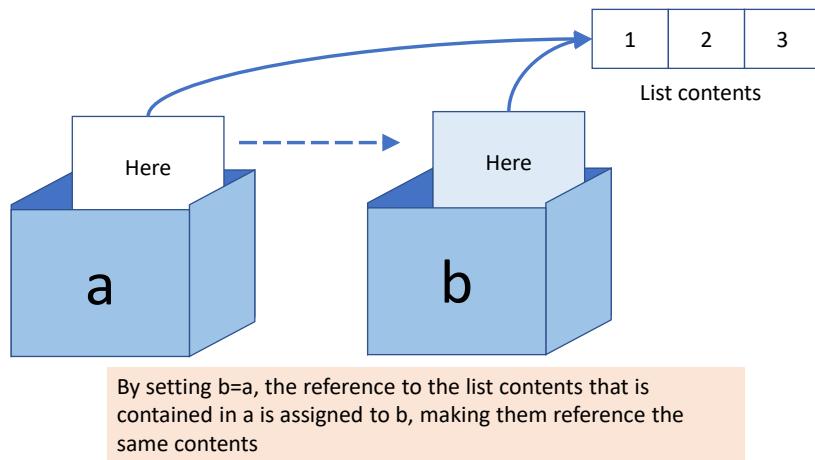


Figure 5-1 List assignment

If you wish to handle `b` as an entity independent of `a`, you will need to explicitly create a copy and assign it (when using lists).

`b = a.copy()`

This same issue can occur when passing lists into a function as arguments. Reference the column titled "Reference & Duplication."

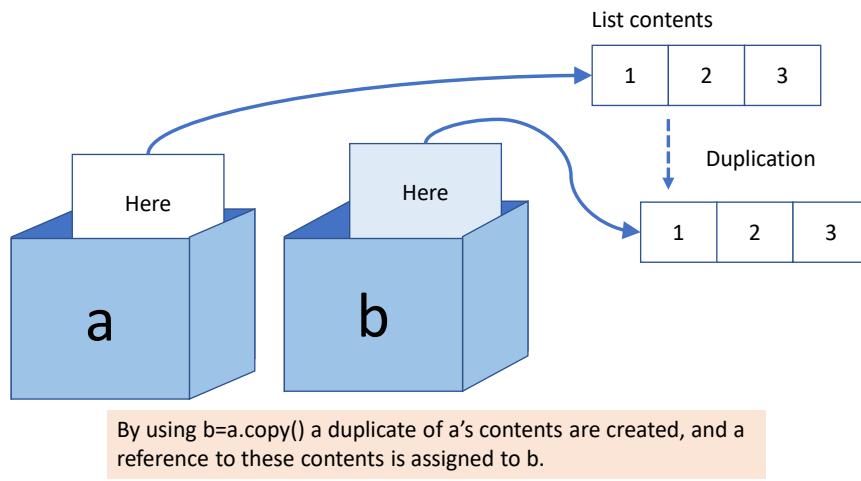


Figure 5-2 Copying and assigning lists

5.10 Mutable and immutable objects

Everyone should now be able to correctly predict how a program with the following code will behave.

```
a = 1
b = a
b = 2
```

```
print(a, b)
```

An important concept regarding data management in Python is the idea of **mutable** versus **immutable** objects.

5.10.1 Numbers and strings are immutable (unchangeable) objects

In Python, numbers and strings are what are known as **immutable objects**. This means that in the third line of the program above, `b = 2` does not overwrite the data (with a value of 1) currently referenced by `b`. Rather, it creates an entire separate entity containing the data “2” and assigns the location of this data to `b`. You can examine their locations in memory using the code below.

```
a = 1
b = a
print(id(a), id(b))
b = 2
print(id(a), id(b))
```

Running this gives the following:

```
>>> a = 1
>>> b = a
>>> print(id(a), id(b))
1434938848 1434938848
>>> b = 2
>>> print(id(a), id(b))
1434938848 1434938880
```

As you can see, `a` and `b` refer to the same location in line 3. However, by line 5 they refer to different locations.

5.10.2 Lists are mutable objects

On the other hand, lists are **mutable objects whose element can be changed**. Because of this, when there are two variables (`a` and `b`) containing references to the same list, any changes to the elements of either of these variables will affect the other.

5.11 Shallow and deep copying

Unfortunately, there are additional issues to consider when using lists. What does variable `b` refer to in the following program?

```
a = [[1, 2], [3, 4]]
```

```
b = a.copy()
```

Let's see what happens when we do the following:

```
b.append([5, 6])  
print(a)  
[[1, 2], [3, 4]]  
print(b)  
[[1, 2], [3, 4], [5, 6]]
```

As you would expect, adding append() to b works without affecting a because we created a copy of a and assigned it to b. Next, try the following:

```
b[0][0] = 0  
print(a)  
[[0, 2], [3, 4]]  
print(b)  
[[0, 2], [3, 4], [5, 6]]
```

This time, the assignment to the element at index [0][0] of b affected a as well. When we check to see what a[0] and b[0] each refer to, we get:

```
print(id(a[0]), id(b[0]))  
3188920520008 3188920520008
```

As you can see, they reference the same object.

This is because the copy() method prepares a new list separate from the target list (copy source) and then transcribes the locations of each element over to this new list. Thus, when the elements themselves are lists, the method does not create copies of them. This kind of copy is called a **shallow copy**, and a copy in which the elements themselves are also copied is called a **deep copy**.

5.12 Visualizing lists

There is a website called Python Tutor (<http://www.pythontutor.com>) where you can input short Python programs and see their behavior (variable usage) visualized. An example can be seen below. Using it to see how lists behave can serve to greatly aid your understanding.

Python 3.6
(known limitations)

```

1 a = [[1,2],[3,4]]
2 b = a
3 c = a.copy()

```

[Edit this code](#)

line that just executed
next line to execute

<< First < Prev Next > Last >>

Done running (3 steps)

Customize visualization (NEW!)

Figure 5-3 Checking how lists behave with Python Tutor

5.13 Keeping Calculation Results in a List

On calculation of square root studied in the previous chapter (p3-1.py) , rewrite the program so as to keep calculation process in a list.

Program 5-1, Keeping calculation process in a list (p5-1.py)

Row	Source code	Notes
1	#Find_the_square_root_of_x	Lines starting with # are comments
2	x=2	
3	#	
4	rnew_=x	Create a list with rnew as an element
5	rnew_list = [rnew]	
6	#	
7	r1_=rnew	
8	r2_=x/r1	
9	rnew_=(r1+r2)/2	
10	print(r1,rnew,r2)	
11	rnew_list.append(rnew)	
12	#	The code below this section simply repeats the above 3 times.
13	r1_=rnew	
14	r2_=x/r1	
15	rnew_=(r1+r2)/2	
16	print(r1,rnew,r2)	
17	rnew_list.append(rnew)	
18	#	
19	r1_=rnew	
20	r2_=x/r1	

<pre> 21 rnew_=_(r1_+_r2)/2 22 print(r1,_rnew,_r2) 23 rnew_list.append(rnew) 24 # 25 r1_=rnew 26 r2_=x/r1 27 rnew_=_(r1_+_r2)/2 28 print(r1,_rnew,_r2) 29 rnew_list.append(rnew) 30 print(rnew_list) </pre>	print the list
---	----------------

Exercise 5-1 Store calculation process in a list

Write Program 5-1 and execute it. After execution, examine the length and elements of rnew_list with Python Shell.

Exercise 5-2 Store estimated accuracy in a list

In Program 5-1, accuracy of rnew can be estimated by $r1 - r2$. Modify the program to calculate the estimated accuracy, store it in another list, say diff_list, and output the list at the end of the program.

5.14 Tuples and dictionaries

Aside from lists, two ways you can handle large amounts of data all at once in Python is by using tuples and dictionaries.

5.14.1 Tuple

Similar to lists, tuples are a data type that consists of multiple elements.

Tuples can be created by simply delimiting the elements on the right-hand side of the equation with commas and assigning them to the variables on the left-hand side.

```
a = 1, 2
a
(1, 2)
```

The right-hand side can also be surrounded by parenthesis.

```
a = (1, 2)
a
(1, 2)
```

Actually, data is treated as tuples in assignments of and function 'return' statements containing multiple values. If the left side has a number of variables equal to the number of elements, each element will be assigned to its respective index.

```
(b, c) = a
```

b

1

c

2

As with lists, the elements of a tuple can be referenced using [] and the correct index.

```
print(a[0])
```

```
1
```

However, tuples are immutable objects, so elements cannot be assigned new values after they are created.

```
a[0] = 2
```

The above code will yield the following error:

```
Traceback (most recent call last):
```

```
File "<pyshell#9>", line 1, in <module>
```

```
a[0] = 2
```

```
TypeError: 'tuple' object does not support item assignment
```

5.14.2 Dictionaries

With lists, you access elements using a numerical index. This is useful when the numerical order of the elements is meaningful. Dictionaries are a data type in which elements are accessed using strings (words). The string that functions as the index is called a “key.”

```
age = {"Yamada":18, "Tanaka":19}
```

```
age
```

```
{'Yamada': 18, 'Tanaka': 19}
```

```
age["Yamada"]
```

```
18
```

Referencing a key that does not exist will result in an error, but assigning it simply adds it to the dictionary.

```
age["Sato"] = 20
```

```
age
```

```
{'Yamada': 18, 'Tanaka': 19, 'Sato': 20}
```

The existence of a key in a dictionary can be checked using the 'in' operator.

```
"Okada" in age
```

False

As with lists, tuples and dictionaries can be used to iterate through for-loops.

5.14.3 Notation for lists, tuples, and dictionaries

Lists, tuples, and dictionaries all use different types of brackets. The correct notation for each type can be seen in the table below.

Table 5-1 Notation for lists, tuples, and dictionaries

Data type	Brackets used	Example	Accessing elements	Mutable/Immutable
Lists	[]	d = [0, 1, 2]	d[0]	Mutable
Tuples	()	d = (0, 1, 2)	d[0]	Immutable
Dictionaries	{ }	d = {"a":1, "b":2, "c":3}	d["a"]	Mutable

6. Control Flow

6.1 Learning goals of this chapter

In this chapter, you will learn the following methods for controlling the execution of a program.

1. Repeated processing and `range()` functions using `for` and `while` loops
2. Branching using `if` statements
3. Error handling with `try` statements

In addition, you will learn the following things which are related to the above points

4. How to write conditional expressions
5. Getting input from the keyboard using the `input()` function
6. Mathematical functions in Python
7. Format designation for outputted text

There is a lot to learn in this chapter, but the material covered will show up in many programs throughout the following chapters. You should be able to pick up the material naturally after seeing many instances of it in use.

It isn't necessary to learn all the fine details at this point. It is important to separate the concept of "**what can this code do**" from the **experience of actually writing it**. If you remember what certain code can do and how to write it in a general sense, you can always check out the fine details in your textbook when the need arises.

6.2 Repeated processing using for-loops

One of the main objectives of programming is to have computers automatically do things that are difficult and/or repetitive for people to do by hand. for-loops are an important method for programming the repetitive parts. Those of you who are familiar with C will notice Python's 'for' statement has a slightly different syntax, but it is easier to use because you can easily write iterations over elements of a list.

6.2.1 Performing a fixed number of repetitions using a for-loop and the range() function

The times that computers can show their true might through programming is when they are able to perform a lot of processing at a very high speed. However, using sequential execution learned in the Chapter 3, you need to write each and every step that the computer executes. Program 4-1 for solving square roots in Chapter 4 repeated the exact same code four times. Here you will learn how to use a for-loop with the `range()` function to automate these repetitions.

Exercise 6-1 Apply 'for' statement to the program of solving square root

Write and run the program contained in the table below.

Program 6-1 Program that solves for square roots (ver. 2, p6-1.py)

Row	Source code	Notes
1	#_Find_the_square_root_of_x	Lines starting with # are comments
2	x_=2	
3	#	
4	rnew_=x	
5	#	
6	for i in range(10):	Repeats the code below while iterating i from 0 to 9. Note the colon at the end of line 6.
7	r1_=rnew	In Python, the repeated portion (block) is
8	r2_=x/r1	indented (the recommended amount is 4
9	rnew_=(r1+r2)/2	spaces).
10	print(r1,rnew,r2)	

It is possible to indent large portions of text all at once in the IDLE Editor by selecting the text, holding down the Ctrl key, and pressing the] key (Ctrl-]). Text can be unindented by using the Ctrl-[shortcut.

6.2.2 Writing for-loops¹

The word “for” has many different meanings. In the context of programming, thinking of it as “for the sake of” can make things difficult to understand. It is better to think of it as closer to its meaning that is synonymous with “regarding.” for-loops in Python are written in the following manner.

```
for target variable in range of repetition :
    Repeated block
```

In the p6-1.py example above, the target variable is 'i', the range of repetition is 'range(10)', and the block is the indented code in lines 7-10.

The range(10) function generates 10 values from 0 to 9 (index of -1). The for-loop puts the generated values into the variable i and repeats the block.

Translating the for-loop into plain English would yield the following.

For values of the target variable within the range of repetition, repeat the repeated block.

From here onward, explanations of Python’s syntax will be enclosed in a frame like the example above. Fixed expressions will be written in red, and parts that can change based on context will be written in black.

Exercise 6-2 Checking the block

Unindent line 10 from the block in the previous example (p6-1.py) as shown below. Check and explain how the program behaves.

¹for-loops in Python can be written very effectively using lists and other data types. These usages will be introduced later. This chapter will cover using for-loops with the range() function.

Program 6-2 Program that solves for square roots (ver. 2, p6-2.py)

Row	Source code	Notes
1	#Find_the_square_root_of_x	Lines starting with # are comments
2	x=2	
3	#	
4	rnew=x	
5	#	
6	for i in range(10):	
7	r1=rnew	
8	r2=x/r1	
9	rnew=(r1+r2)/2	
10	print(r1,rnew,r2)	Unindent this line from the block

Exercise 6-3 Prank

The repeated portion in the program above (p6-2.py) can be run very quickly because the part that outputs to the terminal has been removed from the for-loop. Change the index of the range() function on line 6 from 10 to 100, 1000, 10000, 100000, 1000000, and 10000000 to see how long it takes to run.¹

6.2.3 Blocks in Python

Multiple line portions that are all executed as a unit are called **blocks**. This concept is very important in the world of programming.

- Blocks in Python are denoted by indenting them all by the same amount. This is one of Python's defining features.
- 'for' statements and other lines that require a subsequent block of code require that a colon (:) be placed at the end of the line.
- As indentation carries significant meaning in Python programs, you should stick to the standard practice of indenting by 4 spaces.
- When 'for' statements and other lines that require a subsequent block of code are entered into the IDLE Editor, it will automatically indent the next lines.
- **Using full-width spaces in an indent will result in an error. Be careful not to do this, as it can be a very difficult error to spot.** Also, while this can depend on the settings of the editor being used, using the TAB key will result in an error if the TAB code is input as is.
- In other languages, like C, blocks are enclosed in { }. Students who are familiar with other languages will need to take care to use the correct notation.

Exercise 6-4 Experience errors (2)

Statements such as 'for' statement that require a succeeding block have to end with a colon ":".

¹ Modern personal computers clock in at the GHz level. At one instruction per clock cycle, this leads to extremely fast processing. However, Python takes longer to process than most programming languages due to the fact that it is run via intermediate representation.

Examine what will happen if you forget to type ":", and run the program. Or also try a mistake of writing semicolon ";" instead of ":". See also "19 Appendix: How to Read Error Messages in IDLE/Python."

Exercise 6-5 Experience errors (3)

In Program 6-1, lines 7 through 10 belong to a same block with a same indentation (four spaces). Examine what will happen if you put less spaces (e.g., three spaces) or more spaces (e.g., five spaces) in line 7, and run the program. See also "19 Appendix: How to Read Error Messages in IDLE/Python."

6.2.4 Controlling the processing within a for-loop

'Break' and 'continue' statements can be used within for-loops in order to abort processing or to skip processing at a specific repetition.

- **break:** Breaks out from the for-loop
- **continue:** Skips the remaining code in the block of the for-loop and continues to the next iteration of the loop.

These statements are used in conjunction with 'if' statements, which enable conditional branching and will be introduced later.

Program 6-3 continue and break (p6-3.py)

Row	Source code	Notes
1	for i in range(10):	
2	if i==1:	Move to the next iteration
3	continue	if i is 1
4	if i==8:	Break from the loop if i is
5	break	8
6	print(i)	

This program results in the output shown below.

0
2
3
4
5
6
7

Exercise 6-6 Explanation of continue and break

Explain the output seen above using the source code.

6.2.5 range() function

To be precise, range is implemented as a class and not a function. However, as it is often used

similarly to a function, we will refer to it as the range() function in order to facilitate easier understanding. range() generates a sequence of numbers over a set interval. However, you cannot know exactly what values are generated by merely looking at the calling of the range() function itself. The generated values can be checked by creating a list.

Inputting

```
list(range(10))
```

into the Python shell yields

```
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
```

The range() function can be used in three different ways based on what arguments are passed to it. These usages can be seen below.

- Only an ending value is passed as an argument. This takes the form

```
range(ending_value)
```

as seen above. This starts at 0 and stops at the integer before the ending value.

Students who aren't as familiar with programming languages may feel that it's odd that **it starts with 0** and that the **ending value is not included**. Please refer to the column titled "Starting from 0" for information about this. The **total number of numbers generated still matches the ending value**, so it isn't that difficult to remember. It is standardized throughout Python to start with 0 and stop at the value before the specified end point.

- Both a starting value and an ending value are passed as arguments.

```
range(starting_value, ending_value)
```

The starting value is included, but the ending value is not. A comma must be placed between the two arguments. Placing a half-width space between the arguments will make it easier to read.

- A starting value, ending value, and step width are passed as arguments.

```
range(starting_value, ending_value, step_width)
```

Exercise 6-7 range() function

Practice the three usages of the range() function in the Python shell using list() as shown above.

6.2.6 Calculating sums

In the previous example, the range function was merely used to specify the number of repetitions, and the target variable was not used in any particular way. In this example, we will examine a program that actually utilizes the target variable.

Program 6-4 Calculating sum (p6-4.py)

Row	Source code	Notes
1	sum=0	Sets sum to 0
2	for i in range(10):	i goes from 0 to 9
3	sum=sum+i	adds i to the sum
4	print(sum)	displays the sum

Exercise 6-8 Calculation of sum

Try running Program 5-4. Also, try changing the scope of the sum. Line 3 can also be written as `sum += i`. Try this out for yourself.

6.2.7 Nested for-loops

Values for two-dimensional structures such as tables, which contain rows and columns, can be generated by nesting a for-loop within the block of another for-loop. For example,

Program 6-5 Nested for-loops (p6-5.py)

Row	Source code	Notes
1	<code>for i in range(3):</code>	
2	<code> for j in range(3):</code>	
3	<code> print(i,j)</code>	

Running the code above yields the following output:

0 0

0 1

0 2

1 0

1 1

1 2

2 0

2 1

2 2

Please note that the target variable for the inner for-loop is different than that of the outer for-loop.

Exercise 6-9 Nested for-loops

Try and find out what happens when the variable `i` is used as the argument for the `range()` function (change it to `range(i)`) in line 2.

6.2.8 Using for-loops to manage lists

1) How to combine list length with the range function

The elements of a list can be accessed in order with a for-loop by using `range(len(a))` to generate

each element. For example:

```
a = [5, 1, 3, 4]
for i in range(len(a)):
    print(i, a[i])
```

yields

```
0 5
1 1
2 3
3 4
```

2) How to directly use lists with a for-loop

If you simply desire to reference the element values, the code below would also suffice.

```
a = [5, 1, 3, 4]
for d in a:
    print(d)
```

yields

```
5
1
3
4
```

In this case, the contents of the elements are passed to d, so changing d does not change the list's contents. When you wish to update the elements of a list, you can access them using their index.

3) How to use the enumerate function

The enumerate function is used in cases where you want to use both the index of an element and its value.

```
a = [5, 1, 3, 4]
for i, d in enumerate(a):
    print(i, d)

0 5
1 1
2 3
3 4
```

Exercise 6-10 Solving for averages

To solve for the average value of a list whose elements are numbers, you could use the following code:

```
a = [5, 1, 3, 4]
sum = 0
for i in range(len(a)):
    sum += a[i]
average = sum/len(a)
print(average)
```

The result of this code is:

3.25

Exercise 6-11 Change access to list elements

Rewrite the above program in a manner such that it uses a for-loop to use the list directly.

6.2.9 List comprehension using for-loops

Consider a list of numbers risen to the second power.

[0, 1, 4, 9, 16]

You can make this by explicitly writing it out, as done above, or you could use the following code:

```
a = []
for i in range(5):
    a.append(i*i)
```

In addition, Python has another way to do this, called list comprehension, that entails including a for-loop within the list.

`a = [i*i for i in range(5)]`

6.3 Repetition using while-loops

6.3.1 Calculating the square root with specified accuracy

Let's try calculating square roots to a set level of accuracy. Because r1 and r2 lie on opposite sides of the true value, the absolute value of the difference between them, $|r_1 - r_2|$, can be taken to be the

accuracy of the calculation. Let's write the program specifying the error to be no more than 10^{-6} .

Accuracy in this manner, in which you specify a certain number of digits past the decimal point, is known as absolute accuracy. However, in scientific calculations, there are many situations in which it is better to specify a number of significant digits. For more information on this subject, please refer to the column titled "Relative Accuracy."

Program 6-6 Program that solves for square roots (ver. 3, p6-6.py)

Row	Source code	Notes
1	#Find the square root of x	
2	x=2	
3	#	
4	rnew=x	
5	#	
6	diff=rnew-x/rnew	Takes the difference between the two approximations (x and 1 ($=x/x$))
7	if diff<0:	Changes the sign if negative
8	diff=-diff	
9	while (diff>1.0E-6):	Repeats if the difference is larger than 10^{-6}
10	r1=rnew	
11	r2=x/r1	
12	rnew=(r1+r2)/2	
13	print(r1,rnew,r2)	
14	diff=r1-r2	
15	if diff<0:	Recalculates the difference
16	diff=-diff	

Exercise 6-12 Write and run Program 6-6

Running the program should yield the following result:

```
2 1.5 1.0
1.5 1.4166666666666665 1.333333333333333
1.4166666666666665 1.4142156862745097 1.411764705882353
1.4142156862745097 1.4142135623746899 1.41421143847487
1.4142135623746899 1.414213562373095 1.4142135623715002
```

6.3.2 Calculating the square root with an infinite loop

A program that solves for square roots using an infinite loop is shown in Program 6-7. It calculates accuracy and uses an 'if' statement to determine whether or not to exit the loop via a 'break' statement. This program differs from p6-6.py in two ways.

- An end condition is not specified at the beginning of the loop.

- The condition of the ‘while’ statement determines whether to continue, but the condition that determines whether to activate the ‘break’ statement is a condition that judges whether to stop. So, in this manner, the conditions are inverted.

Program 6-7 Program that solves for square roots (infinite loop method, p6-7.py)

Row	Source code	Notes
1	#Find_the_square_root_of_x	
2	x=2	
3	#	
4	rnew=x	
5	#	
6	while True:	
7	r1=rnew	Infinite loop repetition
8	r2=x/r1	
9	rnew=(r1+r2)/2	
10	print(r1,rnew,r2)	
11	diff=r1-r2	
12	if diff<0:	
13	diff=-diff	
14	if diff<=1.0E-6:	break if the absolute value of the difference is less than or equal to 10^{-6}
15	break	

6.3.3 Structure of a while-loop

The format of a while loop, which repeatedly processes a block of code as long as the given condition remains true, is as follows:

```
while conditional expression:
```

```
    Block of code
```

The condition is checked before the block of code is executed. This is why, in the example above, the value of diff is calculated both before entering the while loop and inside of it. Details regarding how to write conditional expressions will be introduced in the coming sections.

As with for-loops, ‘break’ and ‘continue’ statements can be used when you wish to break from the loop or enter the next iteration.

6.3.4 Infinite loops

You will also frequently encounter instances in which while loops are used in the manner seen below.

```
while True:
```

```
    Block containing a break statement
```

In this usage, the conditional expression is the constant True, meaning that the condition is always

satisfied. This means that the while-loop itself will continue infinitely. As such, you need to include a condition to exit the loop in the form of a ‘break’ statement within the block.

If the break condition is not met, execution of Python will need to be forcibly stopped. **You can do this by using the keyboard shortcut Ctrl-C.**

6.4 Branching using 'if' statements

6.4.1 Structure of an 'if' statement

'if' statements can be used in a few different ways. The most basic is to execute a block of code if the condition in the 'if' statement is met. In addition to this, you can include a block of code to execute if the condition is not met (else), and you can even include yet another condition to evaluate if the initial condition is not met (elif, meaning else if).

```
if conditional expression:  
    Block to be executed if the condition is true
```

```
if conditional expression:  
    Block to be executed if the condition is true  
else:  
    Block to be executed if the condition is false
```

```
if conditional expression 1:  
    Block to be executed if conditional expression 1 is true  
elif conditional expression 2:  
    Block to be executed if conditional expression 1 is false  
        but conditional expression 2 is true  
else:  
    Block to be executed if both conditions are false
```

It is worth noting that Python does not have an equivalent to the switch statement found in C in which you can evaluate three or more conditions to switch between many blocks of code. You can achieve similar branching using multiple ‘elif’ statements.

6.4.2 How to write conditional expressions

1) Comparing numerical values

Perhaps the most common condition is a comparison of numerical values. The operators that can be used to compare numerical values can be seen in the table below.

Table 6-1 Comparison operators in Python

Operator	Meaning	Notes
<code>==</code>	Equivalent	Two equals signs. This is to differentiate it from the assignment operator, which is a single equals sign.
<code>!=</code>	Not equivalent	2 characters
<code>></code>	Greater than	
<code><</code>	Less than	
<code>>=</code>	Greater than or equal to	2 characters
<code><=</code>	Less than or equal to	2 characters

The equivalence operator is two equals signs (`==`). Please take mental note of this, because it is easy to mix up with the assignment operator (`=`).

Also, it is worth noting that floating-point numbers are in many cases merely approximations. As such, the equivalence operator can potentially produce unexpected behavior. In order to avoid this, try to make determinations using inequalities when possible.

2) Comparing strings

The operators above can also be used with strings. However, please note that string values are determined by their character encoding (Unicode) number, so make sure to keep this in mind when comparing strings in this manner.

In addition to the above, you can use “`in`” to check whether the string on the left is included within the string on the right. For example,

`'a' in 'abc'`

returns

`True`

3) Logical operations

The logical operators “`and`,” “`or`,” and “`not`” enable you to combine multiple conditions.

4) Prioritizing operations with ()

Python has a defined order of operations:

- Arithmetic operations are prioritized over comparison operations
- Comparison operations are prioritized over logical operations

It is good practice to use `()` in order to make your programs easier to read by explicitly stating the order of operations. For example:

`a == 1 and b != 0`

The code above behaves exactly the same as the code below, but the latter is easier to read.

(a == 1) and (b != 0)

6.4.3 Nested 'if' statements

Just like how 'for' statements are often nested within other 'for' statements, 'if' statements are also frequently used in this manner. The following two programs make the same determinations but are written in different ways.

Program 6-8 Forking using multiple conditions (p6-8.py)

Row	Source code	Notes
1	a=1	
2	b=0	
3	if(a==1)and(b==0):	
4	print("YES_a==1and_b==0")	Forking with multiple conditions

Program 6-9 Forking with nested 'if' statements (p6-9.py)

Row	Source code	Notes
1	a=1	
2	b=0	
3	if a==1:	
4	if b==0:	
5	print("YES_a==1and_b==0")	Forking with nested "if" statements

Exercise 6-13 Experience errors (4).

It is a common mistake of writing an assignment operator "=" instead of the comparison operator "==" in a "if" statement. Examine what will happen if you write "if a = 1: " in the third line of Program 6-9 and run it. See also "19 Appendix: How to Read Error Messages in IDLE/Python."

6.5 Termination of the Python program

Python programs terminate upon executing the final row, but one can use the `exit()` function from the `sys` module in the manner seen below if one wishes to end a program partway through. One can return a termination code to the location that called the program by passing an argument through the `exit` function. Generally, a value of 0 is used for normal termination and other values are used for abnormal termination. The function defaults to 0 if no argument is specified.

It is worth noting that the `exit()` function called without the module stops execution in the Python shell.

Program 6-10 Termination of the Python program (p6-10.py)

Row	Source Code	Notes
1	import sys	import sys module
2	for i in range(5):	
3	print(i)	
4	if i==3:	If i is 3, terminate
5	sys.exit()	program using
6	print("end")	sys.exit()

Executing this gives the result below. One can see that the program terminates when i is 3.

```
0
1
2
3
```

6.6 Input from the terminal

So far, we've built the number whose square root we want to find into the program itself. Let's consider adding input from the terminal. Below is the Python shell screen. Red text is input, and blue text is output.

Python shell screen	Notes
<pre>>>> a = input("*** ") *** sss >>> a 'sss' >>> type(a) <class 'str'> >>></pre>	<p>Change the input prompt string to <code>"*** "</code> and then accept input via the <code>input</code> function and assign it to a</p> <p>Input sss</p> <p>Evaluate a</p> <p>Retrieves the data type of a using the <code>type</code> function</p> <p>Displays that a is a string (str)</p>

The argument of the `input` function (the string within the parentheses) is the string that will be displayed. The function's return value (the result of the function call) is a string.

In order to obtain numerical data, convert it to the appropriate type using `int()` or `float()`.

In the square root program from before, change the part that sets the value of `x` to

```
x = input("Find the square root of ")
x = float(x)
```

You could even write this in one line like so:

```
x = float(input("Find the square root of "))
```

This enables you to store the numerical value input into the terminal within the variable `x`.

Exercise 6-14 Input number from terminal

Modify p6-6.py so that it solves for the square root of the number input through the terminal.

Open p6-6.py or p6-7.py and select Save As in the File menu to create a new program named e.g., p6-6-1.py or p6-7-1.py.

6.7 Handling errors

When something that cannot be interpreted as a number is passed through the float() or int() functions as an argument, it results in a ValueError. If you have not specified what should be done in such a case, Python will suspend processing of the program at this point. You can make use of a 'try' statement to deal with errors that may arise in a program.

The following program continuously accepts input and handles errors in order to only output (print(x)) positive numbers. This program contains an infinite loop that lacks an explicit stoppage condition. **Input Ctrl-C to stop the program.**

Program 6-11 Program that checks user input (input_check.py)

Row	Source code	Notes
1	while True:	Infinite loop
2	x = input("Enter positive number")	
3	try:	Put the part that can give an error within the try block
4	x = float(x)	Handles a ValueError
5	except ValueError:	Make sure to capitalize Letters when appropriate
6	print(x, "can't be converted to a number")	Handles other errors
7	continue	
8	except:	Ends the program. This is the end of the try block.
9	print("Unecpected error")	
10	exit()	Checks whether the input is positive
11	if x <= 0:	Continuation of the while-loop
12	print(x, "is not positive")	
13	continue	
14	# Below is the result of receiving a proper input	
15	print(x)	

Exercise 6-15 Reviewing Error Handling

Run the above program and see how it responds after receiving various inputs.

6.7.1 Structure of a 'try' statement

Blocks that can generate exceptions are put within 'try' statements, and specified exceptions are placed within 'except' statements with a corresponding block. An 'except' statement that does not specify an exception type will activate for any exception that is encountered (except for exceptions

specified above it).

```
try:
    Block which will require exception handling
except exception:
    Block to be processed when the specified exception occurs
except:
    Block designed to handle all exceptions besides the ones specified above it
```

6.7.2 Always be suspicious of external input

The programmer cannot control the external input that they receive. Programs that are only written to be able to handle anticipated input are often unable to properly handle unexpected input. This often leads to incorrect results. It is **very important that you always distrust external input**. You should ideally always check its validity and include appropriate contingencies for any potential errors that can arise from unanticipated input.

6.8 Mathematical functions in Python

In the examples thus far, I've been explicitly calculating the absolute value of the calculation error diff by changing the sign if the number is negative, like so:

```
if diff < 0:
    diff = -diff
```

Python is equipped with an absolute value function, so this can be written in just one line:

```
diff = abs(diff)
```

In addition, Python is equipped with a library (module) containing many sorts of mathematical functions. To use this, simply write

```
import math
```

to import the module before you use it. Constants and functions defined in the math module can be called by writing the module name followed by a period and the name of the function or constant you wish to call. For example:

```
math.pi
3.141592653589793
math.sqrt(2)
1.4142135623730951
```

The examples above are for mathematical constant pi and obtaining a square root.

Exercise 6-16 Use of math module

Mimic the examples above and play around with the math module yourself within the Python shell.

6.9 Converting numbers and strings; Combining strings

We have used the `input()` function to obtain a string followed by the `int()` or `float()` functions to convert the string to a number. Additionally, you can also use the `str()` function to convert numerical data to a string. The `format()` method, which will be explained below, can be used in cases when you wish to specify the format. These conversion methods are summarized in the table below.

Table 6-2 Conversions between numbers and strings

Conversion	Function	Example	Notes
String to Integer	<code>int()</code>	<code>a = int("123")</code>	An improper string will result in a <code>ValueError</code>
String to Floating-point number	<code>float()</code>	<code>a = float("123.4")</code>	Same as above
Integer / Floating-point number to String	<code>str()</code>	<code>s = str(123.4)</code>	<code>str()</code> can also convert lists and other various types of objects into strings as well.

It is worth noting that numerical values and any other non-string values passed to the `print` function are automatically converted into strings.

Strings can be connected by using the “+” operator. In addition, strings can be repeated by using the “*” operator in conjunction with an integer. Also, you can combine a number with a string by using the “+” operator and the `str()` function.

Table 6-3 Connecting and repeating strings

Operation	Operator	Example	Result
Connecting strings	+	<code>"abc" + "def"</code>	<code>"abcdef"</code>
Connecting strings and numbers		<code>"abc"+str(1.2)</code>	<code>"abc1.2"</code>
Repeating strings	*	<code>"abc"*2</code>	<code>"abcabc"</code>

6.10 Format specification when displaying a number

When Python’s `print()` function displays a numerical value, a number of digits that matches the number is automatically selected. It is possible for the user to specify both the number of digits and the format with which the number is displayed. A concrete example can be seen below:

```
c = 2.99792458E8
na = 6.02214076E23
form = "Light speed is {0:12.8g} m/s, Avogadro's number is {1:12.8g} mol**(-1)"
print(form.format(c, na))
```

executing the above code, we obtain:

```
Light speed is 2.9979246e+08 m/s, Avogadro's number is 6.0221408e+23 mol**(-1)
```

The above code enables you to pick both the number of digits and the format displayed¹.

- The right side of the third line is the string that specifies the format. **The portion enclosed in {} is the format to which the number will be converted.**
 - For example, {0:12.8g} acts upon the 0th element (the number before the colon in the format) of the argument of the **format method** below it,
 - displaying at least 12 digits and going to 8 digits (only 8 digits are displayed to the user) past the decimal point in g format (one of the formats used to display floating-point numbers).
 - Existing formats include 'd' format, which is used to display integers in base 10, 'e' format, which is used to display floating-point numbers using exponent representation, and 'f' format, which displays in fixed-point representation. 'g' format switches between both of these based on the value of the number.
- The `form.format(c, na)` on the fourth line generates a string in which variables c and na are converted to strings according to the format specified within form. This code calls the `format` method, which is a method belonging to string variables (form in this case). This method is called by connecting it to the string it acts upon with a period, i.e., “.”.

¹ The International System of Units (SI) announced with its 2018 amendments that as of May 20, 2019, The International Prototype of the Kilogram would be replaced by a new definition of the kilogram based on physical constants. The values for the speed of light and Avogadro's number used in this example were not determined by actual measurements, rather they are defined to be certain quantities.

7. Making Kyoto Intersections

7.1 Learning goals of this chapter

In this chapter, we will use 'for' statements and lists to practice. we will be going through an example that deals with Kyoto's intersections, which have a grid-like structure.

7.2 Creating Kyoto's intersections

Play around with the following example, which uses 'for' statements to handle lists. Be careful if you decide to write the street names in Japanese characters, as the code will then mix half-width and full-width characters. Note that aside from place names, everything is written using half-width characters (including spaces).

Program 7-1 Making Kyoto intersections (p7-1.py)

Row	Source code	Notes
1	tozai = ["Sanjyo", "Shijyo", "Gojyo"]	Only the text in red font uses full-width characters
2	nanboku = ["Horikawa", "Karasuma", "Kawaramachi"]	
3	for i in tozai:	
4	for j in nanboku:	
5	cross = i+j	Concatenate strings using the + operation
6	print(cross)	

Your screen in the IDLE Editor should look like the screenshot below. Make sure that the reserved keywords for and in, the strings (such as "Sanjyo"), and the print function are all colored appropriately.

```
p6-1_en.py - C:/Users/hjkit/Documents/Python Scripts/textbook/en/p6-1_en.py (3.8.3) — ×
File Edit Format Run Options Window Help
1 tozai = ["Sanjyo", "Shijyo", "Gojyo"]
2 nanboku = ["Horikawa", "Karasuma", "Kawaramachi"]
3 for i in tozai:
4     for j in nanboku:
5         cross = i+j
6         print(cross)
7
Ln: 7 Col: 0
```

This will give the following result¹

¹ There are cases in which Kyoto intersections are named with the east-west street said first (such as ShijyoKawaramachi) and there are cases in which the north-south street is said first (like HigashiyamaSanjyo). In this example, we will be generating the names mechanically, so they may differ from the way they are actually said.

[SanjyoHorikawa](#)

[SanjyoKarasuma](#)

[SanjyoKawaramachi](#)

[ShijyoHorikawa](#)

[ShijyoKarasuma](#)

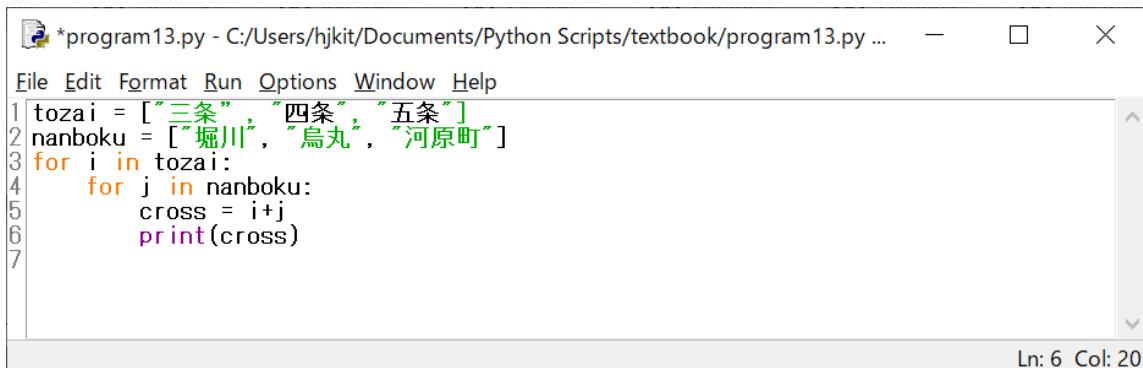
[ShijyoKawaramachi](#)

[GojyoHorikawa](#)

[GojyoKarasuma](#)

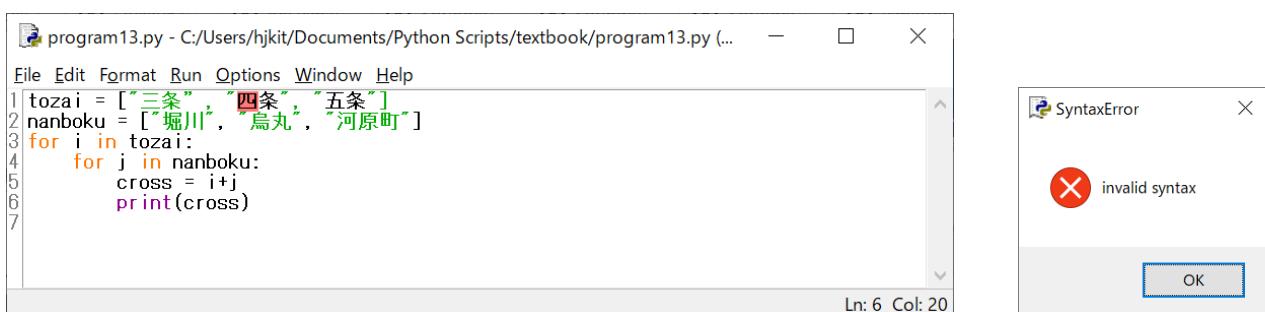
[GojyoKawaramachi](#)

The following example, Street Name in Kanji because of showing a problem of full-width characters.
If you accidentally use a full-width " to close a string, the text that is colored will change.

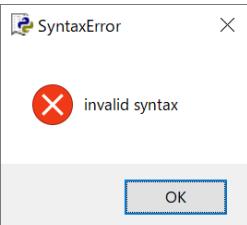


```
*program13.py - C:/Users/hjkit/Documents/Python Scripts/textbook/program13.py ...
File Edit Format Run Options Window Help
1 tozai = ["三条", "四条", "五条"]
2 nanboku = ["堀川", "烏丸", "河原町"]
3 for i in tozai:
4     for j in nanboku:
5         cross = i+j
6         print(cross)
7
Ln: 6 Col: 20
```

Running this will result in an error (invalid syntax). The 四 is displayed in red in the editor. This is because the double quote closing "三条 (Sanjyo)" is in doble-width character, and hence the double quote opening "四条 (shijyou)" is interpreted as double quotes that end the strings following "三条."



```
program13.py - C:/Users/hjkit/Documents/Python Scripts/textbook/program13.py ...
File Edit Format Run Options Window Help
1 tozai = ["三条", "四条", "五条"]
2 nanboku = ["堀川", "烏丸", "河原町"]
3 for i in tozai:
4     for j in nanboku:
5         cross = i+j
6         print(cross)
7
Ln: 6 Col: 20
```



SyntaxError

invalid syntax

OK

7.3 List of lists and how to scan them

Lists in Python can actually contain lists as elements. This fact can be used to create a **data**

structure resembling a table.

```
a = [[1, 2, 3], [4, 5, 6], [7, 8, 9]]
```

Inserting line breaks to make this easier to read yields the following¹.

```
a = [[1, 2, 3],  
     [4, 5, 6],  
     [7, 8, 9]]
```

Display all of list a

```
print(a)  
[[1, 2, 3], [4, 5, 6], [7, 8, 9]]
```

Display the first element of a (the element is a list).

```
print(a[0])  
[1, 2, 3]
```

Display index 1 of the first element of a.

```
print(a[0][1])  
2
```

When tabular data is represented as a list of lists, referencing every element can be achieved through nested 'for' statements. There are multiple ways to do this.

7.3.1 Using indices

```
a = [[1, 2, 3], [4, 5, 6], [7, 8, 9]]  
sum = 0  
for i in range(len(a)):  
    for j in range(len(a[i])):  
        sum += a[i][j]  
print(sum)
```

yields the following:

45

7.3.2 Handling the list directly with 'for' statements

For this example, we will only be referencing the values of the elements, so the code can be written in the manner shown below. The target variable for the 'for' statement is the list itself this time rather

¹ Usually in Python, statements cannot span multiple lines. This is the case in Python 3, but you can clearly see that the example above spans multiple lines. If open brackets such as (do are not closed, then line breaks will not result in an error. In cases where brackets are not used, a \ is required to achieve the same effect.

than a number, so “row” and “element” are used for ease of understanding.

```
a = [[1, 2, 3], [4, 5, 6], [7, 8, 9]]
sum = 0
for row in a:
    for element in row:
        sum += element
print(sum)
```

7.3.3 Creating a table of Kyoto intersections

Exercise 7-1 Creating a table of Kyoto intersections

Use Program 7-1 as a reference to create the table below as a list of lists.

```
cross_table = [["SanjyoKawaramachi", "SanjyoKarasuma", "SanjyoHorikawa"],
               ["ShijoKawaramachi", "ShijoKarasuma", "ShijoHorikawa"],
               ["GojyoKawaramachi", "GojyoKarasuma", "GojyoHorikawa"]]
```

This program can be written in a few different ways. For example:

- Assign the null string "" to each element beforehand, create a list of lists containing the necessary number of elements, and assign each intersection name to an element.

Program 7-2 Making a table of Kyoto intersections (p7-2.py)

Row	Source code	Notes
1	tozai = ["Sanjyo", "Shijo", "Gojyo"]	
2	nanboku = ["Horikawa", "Karasuma", "Kawaramachi"]	
3	cross_table = [["", "", ""], ["", "", ""], ["", "", ""]]	Creates a list of the required size
4	for i in range(len(tozai)):	
5	for j in range(len(nanboku)):	Generates intersection names
6	cross = tozai[i] + nanboku[j]	
7	cross_table[i][j] = cross	Assigns intersection names

After running this, you can look at `cross_table` and see that the table was constructed correctly.

```
>>> cross_table
[['SanjyoHorikawa', 'SanjyoKarasuma', 'SanjyoKawaramachi'],
 ['ShijoHorikawa', 'ShijoKarasuma', 'ShijoKawaramachi'],
 ['GojyoHorikawa', 'GojyoKarasuma', 'GojyoKawaramachi']]
```

As the table in the program above is small, it can be directly defined in line 3. For larger tables, you

can use something similar to the code below. This example creates a table with 5 rows and 4 columns.

```
cross_table = []
for i in range(5):
    row = []
    for j in range(4):
        row.append("")
    cross_table.append(row)
```

- Set `cross_table` to be an empty list and then create a list of intersections for each east-west street. Finally, add (append) this to `cross_table`.

Program 7-3 Making a table of Kyoto intersections (p7-3.py)

Row	Source code	Notes
1	<code>tozai = ["Sanjyo", "Shijo", "Gojyo"]</code>	
2	<code>nanboku = ["Horikawa", "Karasuma", "Kawaramachi"]</code>	
3	<code>cross_table = []</code>	
4	<code>for i in range(len(tozai)):</code>	
5	<code> street = []</code>	List of streets
6	<code> for j in range(len(nanboku)):</code>	
7	<code> cross = tozai[i] + nanboku[j]</code>	Generates intersection names
8	<code> street.append(cross)</code>	Appends intersection to streets
9	<code> cross_table.append(street)</code>	Appends list of streets to table

7.3.4 Displaying the table of intersections

1) Outputting lists

Let's output the list with commas (a half-width comma and a space) inserted between intersections that start with the same east-west street, but with no commas at the end of each line. This would look like so:

```
SanjyoKawaramachi, SanjyoKarasuma, SanjyoHorikawa
```

The `print` function defaults to ending with a line break, but you can specify the **end option** to change the string that displays at the end.

```
street = ["SanjyoKawaramachi", "SanjyoKarasuma", "SanjyoHorikawa"]
for i in range(len(street)):
    if i < len(street)-1:
```

```

print(street[i], end=", ") # Adds ", " to all but the final of the line
else:
    print(street[i]) # Line break at the end

```

While still a bit advanced at this point, you can also pass the entire list to the print function all at once using "*" and specify the delimiter character with the sep option.

```

street = ["SanjyoKawaramachi", "SanjyoKarasuma", "SanjyoHorikawa"]
print(*street, sep=", ")

```

Exercise 7-2 Outputting lists of lists

Create a program that outputs the list of lists of intersection names created in the example above in a manner that conforms to the following conditions:

- Output the intersection names for one east-west street on one line.
- Insert “, ” (a half-width comma and a space) in between the intersection names starting with the same east-west street. However, do not put a comma at the end of each line.

Specifically, the program must yield the following output:

SanjyoKawaramachi, SanjyoKarasuma, SanjyoHorikawa

ShijyoKawaramachi, ShijyoKarasuma, ShijyoHorikawa

GojyoKawaramachi, GojyoKarasuma, GojyoHorikawa

8. Test of skills

8.1 Learning goals of this chapter

- In this chapter, we will test your skills with some practical exercises that span the material covered so far.

8.2 Fine tuning the square root calculation

Exercise 8-1 Fine tuning the square root calculation

Combine input_check.py and p6-1.py to create a program satisfying the following conditions that can solve for square roots. Do not try to grapple with everything listed below all at once. Try to sort out which section of the text is related to each item listed and then update your program to satisfy each condition one at a time. Test your program and confirm it is working as intended after adding each one.

1. Use the `abs()` function to calculate the absolute value.
2. Make the program repeatedly ask for what number's square root to solve for.
3. Make the program notify the user if the input cannot be converted into a number, then have the program ask for another input.
4. Make the program notify the user if the input is below 0, then have the program ask for another input.

If you can, try your hand at the following:

5. Have the program end when the input received from the terminal is “end”
6. Make the calculation accuracy function based on relative accuracy (10^{-6}) instead of absolute accuracy. After implementing this, try solving for the square roots of very small and very large numbers (like 10^{10} and 10^{-10}) and see how the program performs. On relative accuracy, see the chapter of “Relative Accuracy” in the Column Edition.

8.3 Calculating Pi

8.3.1 Leibnitz Formula

The following formula (Leibnitz Formula) regarding Pi is well-known. The right hand side is an alternating series of the reciprocals of odd numbers.

$$\frac{\pi}{4} = \frac{1}{1} - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} \dots$$

The formula used in Chapter 3 and 4 to solve for square roots converges extremely quickly. On the other hand, this formula is quite simple but is known for converging quite slowly. One must calculate 10 times as many terms in order to raise the accuracy of the calculation by just a single digit.

8.3.2 Calculating Pi using the Leibnitz formula

Exercise 8-2 Calculating Pi using the Leibnitz formula

Write a program that uses the Leibnitz formula to solve for an approximation of Pi. Run the program with 1, 10, 100, 1000, 10000, 100000, and 1000000 terms on the right hand side and compare the result to Pi as it is defined by the math module.

It is worth noting that the math module must be imported in order to do this. The value of Pi can be referenced by using math.pi.

```
import math
print(math.pi)
3.141592653589793
```

8.3.3 Hint

In the Leibnitz formula, to solve for the right hand side, for example one can set

```
n = 10
for i in range(n):
```

to 0 initially and use a for-loop where i is incremented by 1 with each loop. The denominator for the i-th term would be $i\%2 + 1$, and the sign would be positive when $i\%2 == 0$ (when i is even), and it would be negative when $i\%2 == 1$ (when i is odd).

8.4 Generating a deck of cards

8.4.1 Set of cards

A deck of cards consists of 4 suits with 13 cards each as well as a joker (we will only add one) added in.

8.4.1 Generating a deck of cards

Exercise 8-3 Generating a deck of cards

Consider the process of creating a list of card names (one for each combination of suit and value) and then randomly shuffling them to create a deck of cards. Complete the program seen below using the program that creates Kyoto intersections as a reference.

Program 8-1 Card deck generation (incomplete, p8-1.py)

Raw	Source Code	Notes
1	import random	import random number module
2	suits = ["♠", "♥", "♦", "♣"]	List of suits
3	ranks =	List of values
4	["A", "2", "3", "4", "5", "6", "7", "8", "9", "10", "J", "Q", "K"]	
5	cards = []	List to hold the generated cards
6	# Generate a card with a suit and value	
7	# and append to cards	
8		
9		
10		
11	cards.append("Joker")	Add the joker
12	print(cards)	print cards
	# Shuffle cards and assign it to deck	
	deck =	
	print(deck)	print deck

8.4.2 Random sorting of the list components

In order to get a random sorting of the list components, we will import the random module and use a function from it called sample. The first argument will be the list itself and the second argument will be the number of list components we want to sort. For example, use

```
import random
a = [1, 2, 3, 4]
b = random.sample(a, len(a))
print(a)
print(b)
```

to get the following. b changes with each execution.

```
[1, 2, 3, 4]
[2, 1, 3, 4]
```

It is worth noting that the random module also contains the shuffle function, but the way that it returns a random sorting of the list passed through it as an argument differs from the sample function. For example, running

```
import random
a = [1, 2, 3, 4]
random.shuffle(a)
print(a)
```

yields different results each time, however it will yield results like the ones seen below.

```
[1, 4, 3, 2]
```

8.5 Intersections in Heian-kyō

8.5.1 Oji (main streets) in Heian-kyō

When the capital was moved to Heian-kyō in 794 A.D., it was made up of Oji (main streets) and Koji (minor streets). A figure depicting only the Oji (main streets) can be seen below.¹ The Suzaku-Oji street, which ran through the center of Heian-kyō from north to south, was around where the Senbon-dori street currently is. Heian-kyō expanded further to the west when compared to the present day Kyoto metropolitan area.

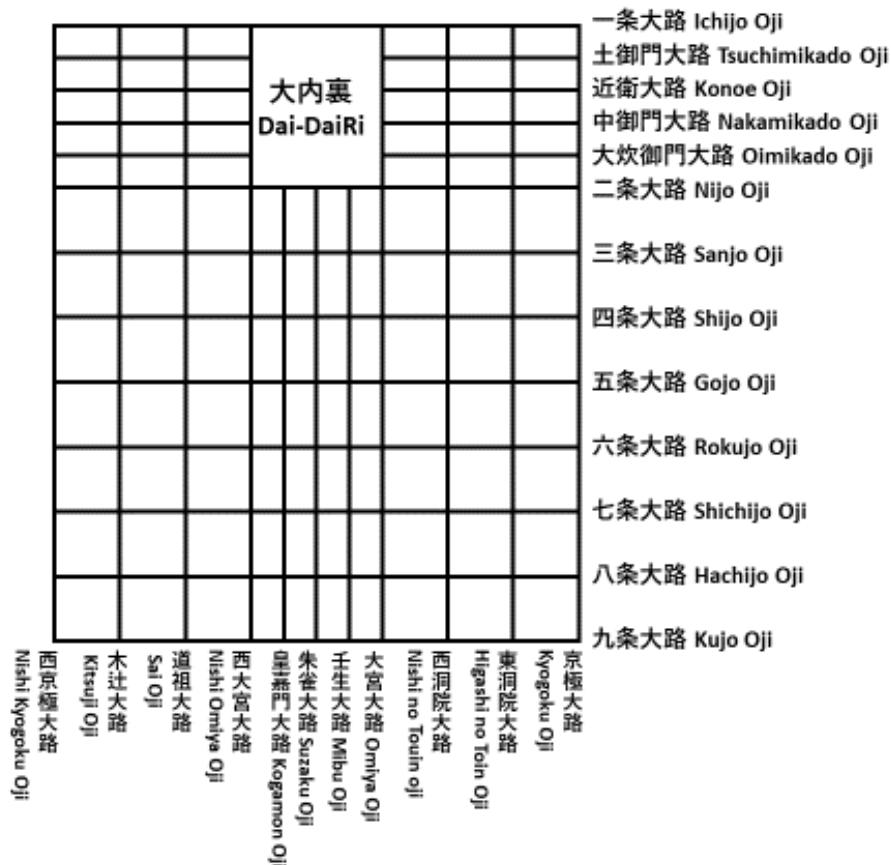


Figure 8-1 Comprehensive diagram of Heian-kyō
(generated by the writer from Reference [14]図一 1 (Figure 1-1))

From these, the Oji (main streets) running east to west arranged starting from the north are as follows.

¹ As it were, this is apparently a blueprint of Heian-kyō, not an exact map of it as it actually was. Those who are interested in maps of Kyoto will find [13] by Mr. Kaneda to be a good reference.

Ichijo Oji, Tsuchimikado Oji, Konoe Oji, Nakamikado Oji, Oimikado Oji,
 Nijo Oji, Sanjo Oji, Shijo Oji, Gojo Oji, Rokujo Oji, Shichijo Oji,
 Hajchijo Oji, Kujo Oji

The Oji (main streets) running north to south arranged starting from the east are as follows.

Kyogoku Oji, Higashi no Touin Oji, Nishi no Touin Oji, Omiya Oji, Mibu Oji,
 Suzaku Oji,
 Kogamon Oji, Nishi Omiya Oji, Sai Oji, Kitsuji Oji, Nishi Kyogoku Oji

8.5.2 Generating Heian-kyō intersections

Exercise 8-4 Generating Heian-kyō intersections

List the intersection names using the format “East-west street name” + “North-south street name.” However, be sure to satisfy the conditions seen below.

- Omit the “Oji (main street)” portion from the intersection names as is generally done in present day Kyoto. For example, as in “Gojo Omiya.”
- List intersections starting in the northwestern corner and going east. Once you reach the end of that east-west street, proceed to the next east-west street immediately to the south starting once again from the west side. For example, going along the Ichijo Oji would yield the result seen below.
 Ichijo Nishi Kyogoku, Ichijo Kitsuji, Ichijo Sai, Ichijo Nishi Omiya, Ichijo Kogamon, Ichijo Suzaku, Ichijo Mibu, Ichijo Omiya, Ichijo Nishi no Touin, Ichijo Higashi no Touin, Ichijo Kyogoku
- Delimit the names with ", " when going from west to east, do not start a new line. Start a new line once you reach the eastern end (do not put a comma at the end).
- There are no intersections within the inner part of the Heian Palace, so just display “****” instead of an intersection name. This special case can also be delimited with a comma. Intersections on the side of the Heian Palace (except the part on the north side that is not a proper intersection) should be displayed. In other words:
- **Display:**
 - Ichijo Nishi Omiya, Ichijo Omiya,
 - Tsuchimikado Nishi Omiya, Tsuchimikado Omiya,
 - Konoe Nishi Omiya, Konoe Omiya,
 - Nakamikado Nishi Omiya, Nakamikado Omiya,
 - Oimikado Nishi Omiya, Oimikado Omiya,
 - Nijo Nishi Omiya, Nijo Kogamon, Nijo Suzaku, Nijo Mibu, Nijo Omiya
- **Hidden:**
 - Ichijo Kogamon, Ichijo Suzaku, Ichijo Mibu,

- Tsuchimikado Kogamon, Tsuchimikado Suzaku, Tsuchimikado Mibu,
- Konoe Kogamon, Konoe Suzaku, Konoe Mibu,
- Nakamikado Kogamon, Nakamikado Suzaku, Nakamikado Mibu,
- Oimikado Kogamon, Oimikado Suzaku, Oimikado Mibu
- Those who have time should try running the prompt below in Anaconda.

python heiankyo.py > heiankyo.csv

However, make the program name heiankyo.py. By doing so, a file called heiankyo.csv should be created. One can open excel by double clicking on this file. The ">" in the command above is a feature of the Anaconda prompt (or more specifically the Windows Command prompt) called redirect that takes the output to the console and inputs it into a file called heiankyo.csv.

8.5.3 Hint

There are various ways one could go about displaying “****” instead of an intersection name. For example, use

- Consider treating from Ichijo Oji to Oimikado Oji as well as anything from Nijo Oji and further south separately.
- If the east-west street is from Ichijo Oji to Oimikado Oji and the north-south street is from Kogamon Oji to Mibu Oji, change the intersection name to “****” etc.

References

- [14] 金田 章裕：古地図で見る京都：『延喜式』から近代地図まで，平凡社（2016, in Japanese）

9. Encapsulation of Processing Using Functions

9.1 Learning goals of this chapter

1. In this chapter, we will use the exercise from Chapter 5 to learn how to take a batch of commands and define it as a function so that it can be used when needed.
2. Learn how to pass values as arguments to functions.
3. Learn how to return a value from a function when it is called.
4. Learn about variables used within functions and the scope within which they have influence.
5. Learn about some general situations in which functions tend to be used.

As with Chapter 5, there is a lot to learn in this chapter. However, you will be able to use the material covered in this chapter in concrete examples throughout the rest of the text. As such, you don't need to worry about learning all the fine details right away. Simply **focus on learning what you can do with the concepts learned in this chapter as well as on building experience writing code using these concepts**. It is always possible to look back through the text to review the fine details as the need arises.

9.2 Let's make an absolute value function

As a simple exercise in defining functions, let's create our own absolute value function like the one we used in a previous chapter.

Program 9-1 Example of an absolute value function (p9-1.py)

Row	Source code	Notes
1	def myabs(x):	Definition of the myabs function, the argument is x
2	if x<0:	
3	x=-x	Flips the sign if x is negative
4	return x	Returns x
5		
6	while True:	This is the main program (the part that runs first when the program is executed)
7	a=float(input(">"))	
8	print(a, myabs(a))	Calls myabs with a as the argument

Program 9-2 Example of an absolute value function (p9-2.py, returns when possible)

Row	Source code	Notes
1	def myabs(x):	Definition of the myabs function, the argument is x
2	if x<0:	
3	return -x	if x is negative, flip the sign and return
4	return x	Returns x
5		

6	<code>while True:</code>	This is the main program (the part that runs first when the program is executed)
7	<code> a=float(input(>))</code>	
8	<code> print(a, myabs(a))</code>	Calls myabs with a as the argument

Exercise 9-1 Create an absolute value function

Write Program 9-1 and Program 9-2 and confirm that they behave as expected.

Exercise 9-2 Experience errors (5).

In Program 9-1 and Program 9-2, function "myabs" assumes that the given parameter is numeral. If you forget calling float() function in line 7 and write as "a = input("> ")", the input data is assigned to variable a as string. Examine what will happen in this case. See also "19 Appendix: How to Read Error Messages in IDLE/Python."

9.3 Format for function definitions

The general format for function definitions is given below.

```
def function name(parameters):
    Explanatory string
    Block executed by the function
    return value returned by the function
```

- Function names are governed by the same rules as variable names (referred to as identifiers). As functions tend to be accompanied by specific actions, verbs are often chosen as function names.
- Parameters are the values that the function receives. They are written using the variable names (parameters) with which they will be referred to within the function. When multiple parameters are specified, they must be separated using “,”.¹
- Even if there are no parameters, the () after the function name cannot be omitted. The () are also necessary when calling a function with no parameters.
- The explanatory string (it is called a docstring) can be omitted. Reference the column titled "Documenting a Program."
- 'return' statements are generally written at the end of the function definition.
- 'return' statements can be included anywhere and are not limited to the block of an 'if' statement that checks for certain conditions or to the end of the definition.
- If the function does not need a return value, you do not need to include a 'return' statement.

9.4 Parameters and arguments

The parameters where the function is actually called are **arguments or actual parameters**, and the

¹ There are other ways to treat variables in Python that will be omitted here.

parameter used internally within the function are also called **formal arguments**. Reference the column titled " Parameters and Arguments."

- Arguments can be variables, equations, and function calls. The equation or function will be evaluated first before the result is passed to the function.
- Arguments and parameters do not need to have the same names.
- If a number, string, etc. is passed to a function as a argument, the value of the corresponding parameter will not be affected even if another value is assigned to the parameter within the function.¹

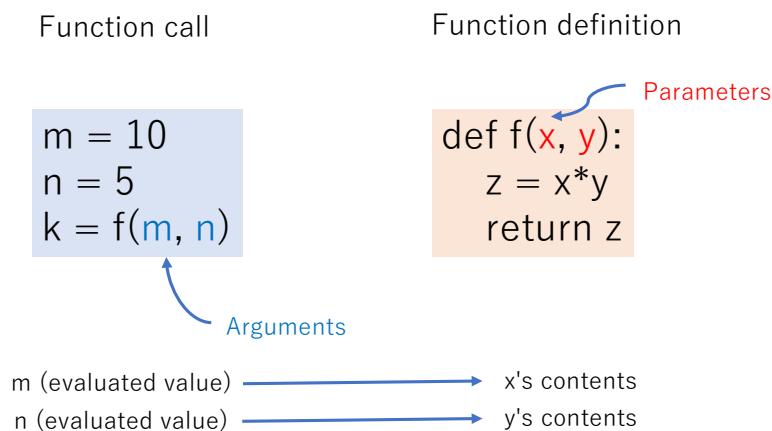


Figure 9-1 Arguments and Parameters

9.5 Return values

The calculated result of a function is returned using a 'return' statement.

- As seen in Program 9-2, it is possible to include multiple 'return' statements within a function definition. However, splitting the return among multiple possible statements can make editing the function difficult.
- **In Python, it is possible to return multiple values by separating them with commas.** When calling the function, multiple variables can be listed, separated by commas, to accept multiple return values. If multiple return values are accepted with a single variable, this variable will contain multiple return values and become a data type known as a tuple.

9.6 From an exercise in a prior chapter

In a prior chapter, you learned how to write a program to solve for square roots as well as how to accept the number whose root it would solve as input from the terminal. Combining these concepts, we dealt with the problem of writing a program that would continually ask for numbers from the terminal and solve for the square root of the inputted numbers. Two potential ways to write a program that continually asks for input from the terminal are explained below.

¹ Lists can be overwritten.

1. Receive input, calculate the square root only when the proper input is received, and repeat by asking for more input.
2. Continually repeat receiving proper input from the terminal followed by solving for the square root of the input.

If you were to program both of these, 1 would need to solve for the square root, and 2 would need to obtain proper input from the terminal before solving for the square root. If you were to assume these actions were performed by the functions `get_positive_numeral()` and `square_root()`, the programs could be written as described below.

1.

```
while True:
    Obtain input x from the terminal and check
    whether it is a positive number
    if positive number:
        r = square_root(x)
        print(r)
```

2.

```
while True:
    x = get_positive_numeral()
    r = square_root(x)
    print(r)
```

Writing a fixed batch of processing as a function like this allows you to **encapsulate** said processing. The advantages of doing this include:

- The program that calls the function becomes much shorter and easier to understand.
- The same processing can easily be performed in different parts of the program.
- Modifying the definition of the function becomes easier when you separate the program where it is used from the program where it is defined.

9.7 Let's write the `square_root()` function

Let's take p6-6.py, which solves for square roots, and turn it into the `square_root()` function.

Program 9-3 Implementation of the `square_root()` function (p9-3.py)

Row	Source code	Notes
1	#	
2	def square_root(x):	
3	<i>'Calculate square root of argument x'</i>	A function that takes a parameter <code>x</code> explanatory string (docstring)

<pre> 4 rnew=x 5 # 6 diff=rnew-x/rnew 7 if diff<0: 8 diff=-diff 9 while (diff>1.0E-6): 10 r1=rnew 11 r2=x/r1 12 rnew=(r1+r2)/2 13 print(r1,rnew,r2) 14 diff=r1-r2 15 if diff<0: 16 diff=-diff 17 return rnew 18 # Main program from here 19 v=2 20 r=square_root(v) 21 print("Result is",r) </pre>	<p>The function definition block extends until line 17. As with p6-6.py, be careful of the indentation.</p> <p>'return rnew,' returns the calculated value</p>
---	--

The result of running this program is shown below.

If you include an explanatory string (docstring) with a function definition in Python, you can display this string by calling the help function and passing the name of the function as the argument.

```

2 1.5 1.0
1.5 1.4166666666666665 1.3333333333333333
1.4166666666666665 1.4142156862745097 1.411764705882353
1.4142156862745097 1.4142135623746899 1.41421143847487
1.4142135623746899 1.414213562373095 1.4142135623715002
Result is 1.414213562373095
>>> help(square_root)
Help on function square_root in module __main__:

square_root(x)
    Calculate square root of argument x

>>>

```

Exercise 9-3 Create a function to solve square root

Make a program that continually solves for square roots with the function square_root().

Exercise 9-4 Create a function to solve square root (2nd)

Define the function get_positive_numeral(), and make program that continually solves for square roots with it as well as the function square_root().

9.8 Treatment of variables within functions

Python treats variables within functions in the following manner. Reference the column titled "

Scope of Variables."

- **Local variables:** Variables defined (assigned) within functions can only be used within those functions. Every time the function is run, these variables will be lost when the function ends.
- **Parameters** are treated as local variables.
- **Global variables:** Variables defined outside of the function can be read to obtain their values.
- **Assignments to global variables:** Within functions, only global variables that are declared with 'global' statement can be assigned values.

Because variables are treated in this manner in Python:

- Variables only temporarily needed within functions can be used freely without worrying about their influence on anything else.
- Operating on global variables can be a primary cause of longer programs being difficult to understand. In Python, reading variables, which is relatively safe, is permitted unconditionally. On the other hand, writing to variables requires an explicit 'global' statement. In this way, Python strikes a good balance between convenience and safety.

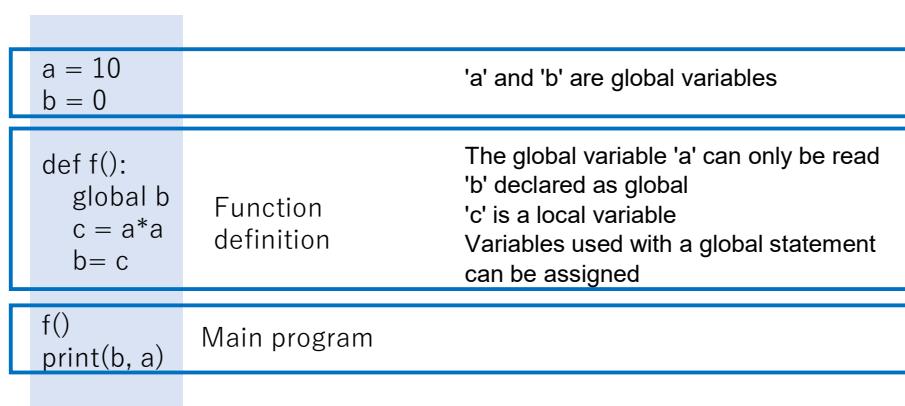


Figure 9-2 Global variables and local variables

9.9 Common uses of functions

Unlike mathematical functions, there are multiple ways in which Python functions are commonly used. The information supplied to the function within () is called the argument, and the value returned by the function is called the return value.

- Pass an argument and use the return value. Similar to how mathematical functions are used.
`y = math.fabs(-2.0)`
- Pass no arguments and do not use a return value. Used to execute a fixed set of commands.
For example, turtle's up() function seen in the next chapter

- Pass arguments but do not use a return value. Used to execute a set of statements that contains changing values.
For example, turtle's forward(100) function seen in the next chapter
- Pass no arguments and use a return value. Used to gain information about the state of something.
For example, turtle's p = pos() seen in the next chapter

There are also functions that **read and write to global variables** as well as functions that **exchange information using lists and other rewriteable arguments**. However, these uses for functions are often referred to as function **side effects**. Because they are often difficult to explicitly state within the source code (particularly the side that calls the function), they have the downside of making programs more difficult to understand.

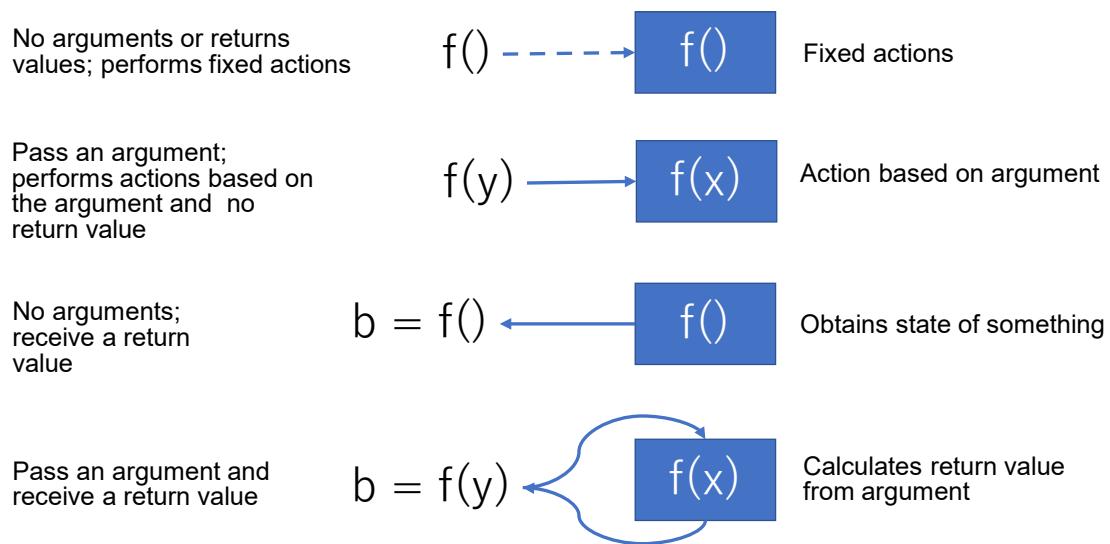


Figure 9-3 Common uses of functions

a = 0	Global variable
def f(): global a a = a+1	Function that operates on global variable
def g(x): x[0] = 0	Function that operates on the contents of a list argument
f() print(a) b = [1,2,3] g(b) print(b)	Main program By calling this function, the contents of both the global variable and the list argument change

Figure 9-4 Function calls and “side effects”

9.10 Function calls and passing function objects

When executing a function defined by a 'def' statement, you write something like `f()` regardless of whether or not the function has arguments. Regarding this, in later chapters, you will run into the function that runs when the mouse is clicked in turtle graphics, or the function that runs when a button is pressed in a GUI program within tkinter in which solely the function name is written. Using this notation does not run the function on the spot, rather it enables you to pass the function in its entirety as an object that can be executed later. In the example below, the function `f` is passed as an argument to the function `F`, and `f` runs within `F`.

```
def f():
    print("f says Hello")

# Function that takes a function as an parameter and runs it

def F(y):
    print("In F, ", end="")
    y()
    # runs f
    f()
    f says Hello
    # passes f to F and runs F
    F(f)
    In F, f says Hello
```

9.11 Default parameters and keyword parameters

9.11.1 Default parameters

Within function definitions in Python, it is possible to specify a value to be implicitly used (default value) in the case that an argument is not passed. This can be done by setting the argument equal to something (using "`=`") within the function definition.

9.11.2 Keyword parameters

When calling a function, arguments are written in order from left to right. However, by writing "argument name = value", you can pass a value for only the specified parameter.

9.11.3 Example

```
def f(a, b=2, c=3):
    return a + b + c
```

f(1,1,1)

3

f(1)

6

f(1, c=2)

5

When programming with tkinter in later chapters, there will be a large number of parameters. Thus, we will be using this method of employing keyword parameters to specify only the necessary ones.

10. Playing with Turtle

10.1 Learning goals of this chapter

1. Learn how to use modules in Python with Turtle.
2. Learn how to use class objects in Python with Turtle
3. Review what you have learned so far through making graphical works with Turtle.
Independently learn how to use the libraries necessary to make these graphical works.

10.2 Modules

Python offers a variety of libraries in the form of “modules.” To use a module, you must first import the module in the Python script. There are a few ways you can do this, as seen below.

10.2.1 Where to put 'import' statements

'import' statements are normally all listed at the beginning of a program.

10.2.2 Importing a module by specifying its name

The math module provides access to mathematical functions. To import it, we write:

```
import math
```

In order to call functions and constants from the module, first write the module name, followed by a dot. For example, to call the “pi” constant, we write:

```
math.pi
```

All modules typically follow this style.

10.2.3 Importing a module using a custom name

An alias is used when you want to refer to a module name in a shortened form. For example, the module tkinter, which will be discussed later, is often abbreviated to tk, as follows:

```
import tkinter as tk
```

Then, you can use the alias tk to refer to the module in your code.

10.2.4 Importing elements from within a module

We will import functions from the turtle module used in this chapter simply by writing:

```
from turtle import *
```

This allows us to use all the functions in a module just by calling the function name. However, it is dangerous to overuse this method, because you may lose track of which module the function or variable belongs to. Reference the column titled "Namespaces."

10.2.1 Be careful not to name programs with the same file name as a module

When Python reads the import command, it searches beforehand in the folder containing the libraries and other files for Python programs with the specified module name.

When this occurs, the current working folder is searched first, so if you create a file called turtle.py, for example, it will be interpreted as a module file and an error will occur. Be careful not to create a Python script in the working folder with the same name as a module.

10.3 Turtle — The time-honored turtle

Turtle graphics allows you to give commands to a turtle (robot) on the screen to move forward, rotate, and such, as well as create a graphical representation of its trajectory.

LOGO, a programming language developed at the Massachusetts Institute of Technology (MIT), has integrated graphics functionality which allows for the visualization of the movement of programs for learning. One of the developers of LOGO, Seymour Papert (1928-2016), is famous for his efforts in teaching children programming. He is quoted as saying:

In many schools today, the phrase "computer-aided instruction" means making the computer teach the child. One might say the computer is being used to **program the child**. In my vision, the **child programs the computer** and, in doing so, both acquires a sense of mastery over a piece of the most modern and powerful technology and establishes an intimate contact with some of the deepest ideas from science, from mathematics, and from the art of intellectual model building.

- Seymour Papert [10], emphasis in bold by the author.

In Japan, a teacher named Mr. Totsuka created a program to process LOGO by himself, and taught it in elementary schools[11]. Other child-friendly programming languages include Squeak (developed by Alan Kay), and Scratch¹, which was developed at MIT. Squeak and Scratch also have turtle graphics functionality. The mascot of Scratch, which is a cat that you can make run around using programming, is descended from turtle graphics. You can also use the Turtle module in Python to have fun with turtle graphics.

Dealing only with numbers can get tiresome, so in this chapter, we will review what you have learned up until now using turtle graphics.

10.4 Python's turtle module

- In Python, turtle graphics is provided as the turtle module.
- It is based on the tkinter GUI environment².
- It can be used in two ways: procedurally, to manipulate a single turtle with function calls, and object-oriented, to handle multiple turtles.

¹The MIT Media Lab Group that developed Scratch is called “lifelong kindergarten.” Isn’t that a wonderful name?

²IDLE, which is used in this course, and the GUI environment introduced below are similar. Tkinter uses the Tcl/Tk GUI library.

- Note: Do not create Python programs with the same file name as the module name (`turtle.py`), or Python will not be able to find the correct module.

10.5 Let's try it out

Write the program in the table below and try running it.

**Program 10-1 Turtle usage example
(`p10-1.py`, Do not save this program as `turtle.py`)**

Row	Source code	Notes
1	<code>from turtle import *</code>	Calls the functions defined in the <code>turtle</code> module.
2	<code>forward(100)</code>	
3	<code>left(90)</code>	
4	<code>forward(100)</code>	
5	<code>left(90)</code>	
6	<code>forward(100)</code>	
7	<code>left(90)</code>	
8	<code>forward(100)</code>	
9	<code>left(90)</code>	
10	<code>done()</code>	End

The `forward()` function makes the turtle move forward, and the `left()` function makes the turtle move left.

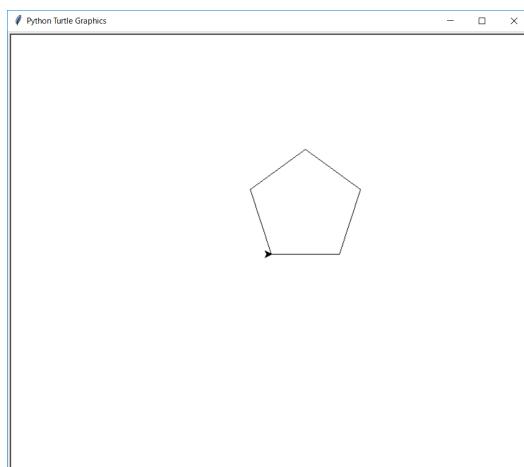
The turtle holds a pen, and when the pen is pressed down (which is the default setting), it marks the path that the turtle takes when it moves.

Exercise 10-1 Draw a regular polygon with n faces

Complete the following program so that it draws a regular polygon with n faces.

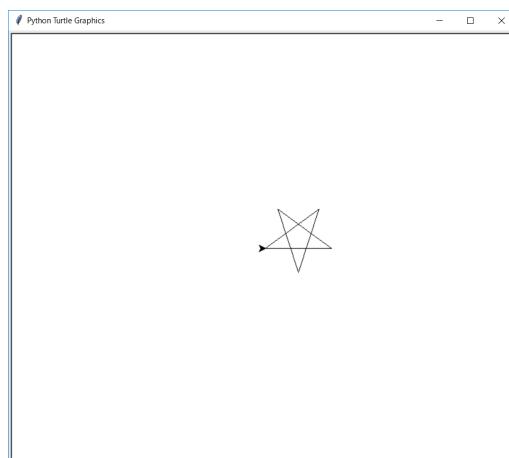
Program 10-2 Program that draws polygons with n faces (incomplete, to be saved as p10-2.py)

Row	Source code	Notes
1	from turtle import *	Calls the functions defined in the turtle module.
2	n=5	Draw a regular pentagon
3	for i in range(n):	Repeat n times
	done()	End



Exercise 10-2 How can you draw a 5-pointed star?

Hint: for regular polygons, the direction the turtle was facing changed so that after completing its circuit, it had made a single revolution. What is needed to draw a 5-pointed star?



Exercise 10-3 Draw regular 7- and 9-sided polygons, and their star equivalents

Make the turtle draw a regular 7-sided polygon, regular 9-sided polygon, and their star equivalents (where the shape made inside of the star has the same number of vertices as the regular polygon equivalent).

10.6 The major functions in the turtle module

The following functions are available. For more details, see

24.1. turtle — Turtle graphics

in the Python documentation.

- forward(d): Move the turtle forward by the specified distance d . fd(d) is the same function.
- back(d), bk(d), backward (d):Move the turtle backward
- right(a), rt(a): Turn the turtle right by a degrees
- left(a), lt(a) :Turn the turtle left by a degrees
- goto(x, y), setpos(x, y), setposition(x, y): Move the turtle to the coordinates x, y
- setheading(a): Set the orientation of the turtle to a degrees
- pendown(), pd(), down(): Pull the pen down (draw when moving)
- penup(), pu(), up(): Pull the pen up
- position(), pos(): Return the turtle's current location as a two-dimensional vector. Two variables are output as return values, as shown below.

```
x, y = pos()
```

- heading(): Return the turtle's current orientation
- isdown(): Returns True if the pen is down, False if the pen is up.

Exercise 10-4 Categorize the above functions following the usages shown in Section 9.9.

10.7 Moving multiple turtles

10.7.1 Example program

Program 10-3 Moving multiple turtles (p10-3.py)

Row	Source code	Notes
1	from turtle import *	Calls the functions defined in the turtle module.
2	t1=Turtle()	Creates the first turtle t1
3	t2=Turtle()	Creates the second turtle t2
4	t1.color('red')	Sets the color of t1 to red
5	t2.color('blue')	Sets the color of t2 to blue
6	for i in range(180):	

7	<code> t1.forward(5)</code>	Moves t1 forward 5 steps
8	<code> t2.forward(3)</code>	Moves t2 forward 3 steps
9	<code> t1.left(2)</code>	Turns each turtle left twice
10	<code> t2.left(2)</code>	
11	<code>done()</code>	End

10.7.2 Using Class Objects

In this example, each turtle is created as an object of the Turtle class.

A turtle has a number of attributes, such as “location” (coordinates), “direction,” “pen up” or “pen down,” and “pen color.” In order to program a turtle, you need to know these attributes and be able to change them.

Objects with a class type are a good way to describe such operations. By using multiple turtles, you will be able to understand the key points of using class objects.

1) 1) Creating a turtle

Objects of the Turtle class are created with the `Turtle()` command. The function that creates a class object is called a constructor, which in this case creates a turtle (a construct)¹. In the example below, by assigning the generated object to the variable `t1`, the turtle can be referred to by the variable `t1` thereafter.

```
t1 = Turtle()
```

2) 2) Manipulating the Turtle

The way to know the state of the turtle, or to change its state, is to call a “method.” Methods are invoked by writing “.” followed by the method name (and arguments) of the object variable. Think of it like a function call, except that an object is the target.

```
t1.forward(10)
```

3) 3) Determining the Turtle's Attributes

To find out an attribute of the turtle, call a method that returns the attribute, and assign the result to an appropriate variable.

```
x, y = t1.pos()
```

This can also be written as follows

```
(x, y) = t1.pos()
```

¹ In computer programming, you will often encounter terms with suffixes such as -er, because personifying expressions are useful for expressing the things you ask a computer to do. The word “computer” also used to mean a person in charge of calculations (a calculator) until the advent of mechanical calculators.

10.8 Tips for creating your project

10.8.1 Responding to Mouse Clicks

Define a function to be executed when the mouse is clicked, and pass the defined function object to the `onscreenclick()` function.

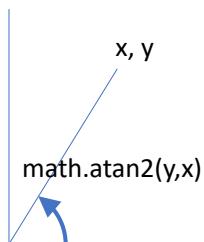
Program 10-4 Responding to mouse clicks in turtle graphics (p8-4.py)

Row	Source code	Notes
1	<code>from turtle import *</code>	
2	<code>def come(x,y):</code>	
3	<code> xx,yy = pos()</code>	Defines a function to be executed when the mouse is clicked, with the parameters being the position of the mouse cursor when clicked.
4	<code> newxy = ((xx+x)/2,(yy+y)/2)</code>	
5	<code> print(x,y)</code>	The function definition ends here.
6	<code> goto(newxy)</code>	
7	<code> onscreenclick(come)</code>	Set up the function to be called when the mouse is clicked (note that there is no () after "come").
8	<code> done()</code>	

10.8.2 Converting Coordinates to Angles

To find the angle from the x and y coordinates in a given direction, Python provides a function called `atan2` in the `math` module.¹ The argument is the previous vertical coordinate. The return value is in radians, so to use it with `turtle`, where the angle is set in degrees, we convert it as follows.

```
import math
y = 2
x = 1
angle = math.atan2(y, x)*180/math.pi
```



¹ To calculate coordinates from angles, you can use the trigonometric functions `cos` and `sin`, but since these are not suitable as inverse trigonometric functions, `atan2` has been implemented as an extension of the inverse tangent function (`atan`).

10.8.3 Using Random Numbers

Random motion is another interesting thing to visualize.

- To use random numbers in Python, use the random module.
- Refer to the column titled "Random Numbers."
- Here is an example of turtle graphics using random numbers (see `random_turtle.py` for more details).
- The turtle is stopped by a mouse click.

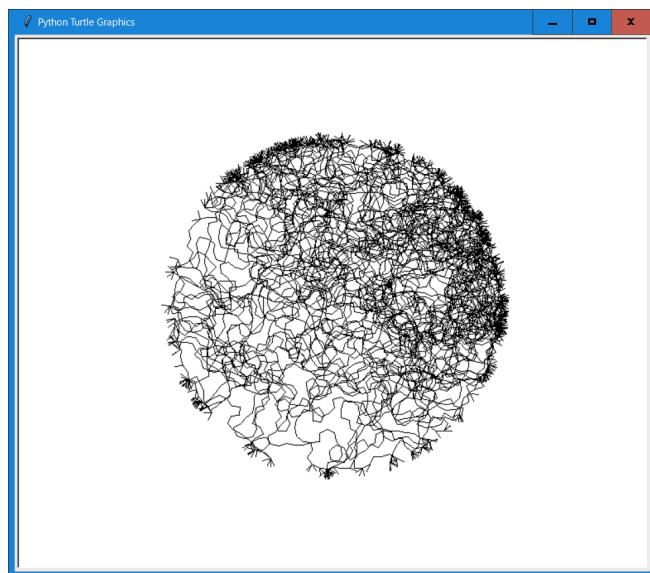


Figure 10-1 A result of executing `random_turtle.py`

10.8.4 Drawing Fractals

A shape in which one part is similar to the whole is called a fractal. Fractal figures are interesting both for what they are drawn as and for the algorithms that draw them.

- Use recursion (calling a function within the function itself).
- See the column titled "Recursion."
- See `detour.py` and `turtle-tree.py`. The recursive calls are marked in red.

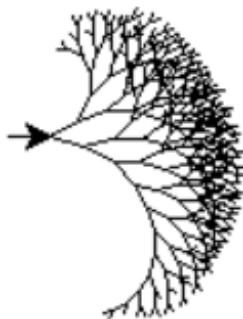


Figure 10-2 A result of executing turtle-tree.py

10.8.5 Defining the shape of a turtle

1) The tortoise and the hare¹

The former Toyosato Elementary School building in Shiga Prefecture is famous due to William Merrell Vories' architecture, but a little known fact is that one can find a tortoise and hare engraved into the banisters.



**Figure 10-3 Former Toyosato Elementary School building and banister
(10/16/2016 Kita Photography)**

One can make a good turtle shape with Python's Turtle Graphics, but it is hard to make a good hare. However, one can define and use one's own as seen in the example below.

2) Example hare and card suits

By default, one has access to six shapes in Turtle Graphics: arrow, "turtle", "circle", "square", "triangle", and "classic". One can register additional shapes by using the register_shape method seen on the screen. In order to define the shape, one must supply a name and a tuple of x and y coordinates that make up the outline of the shape. One can get the screen by using the getscreen

¹ In Japanese, we use the word “KAME” both for turtle and tortoise, and “USAGI” both for rabbit and hare.

function. An example of a hare can be seen below.

```
rdata = ((0, 16), (-2, 14), (-3, 11), (-3, 6), (-2, 5), (-2, 7),
         (-1, 10), (-2, 7), (-2, 5), (-3, 6), (-3, 10), (-4, 13),
         (-5, 13), (-4, 2), (-5, -10), (-4, -10), (-3, -4),
         (0, -5), (3, -4), (4, -10), (5, -10), (4, 2), (5, 13),
         (4, 13), (3, 10), (3, 6), (2, 5), (2, 7), (1, 10),
         (2, 7), (2, 5), (3, 6), (3, 11), (2, 14))

getscreen().register_shape("rabbit", rdata)
```

Program 10-5 Defining the shape of a turtle (p10-5.py)

Row	Source Code	Notes
1	# 2 #_Output_various_turtle_shapes 3 # 4 from_turtle_import_* 5 #_hide_default_turtle 6 ht() 7 #_ Define_a_hare_shape_consisting_of_tuples_with_(x,y)_coordinates 8 #_rabbit_shape_data 9 rdata=((0,16),(-2,14),(-3,11),(-3,6),(-2,5),(-2,7), 10 (-1,10),(-2,7),(-2,5),(-3,6),(-3,10),(-4,13), 11 (-5,13),(-4,2),(-5,-10),(-4,-10),(-3,-4), 12 (0,-5),(3,-4),(4,-10),(5,-10),(4,2),(5,13), 13 (4,13),(3,10),(3,6),(2,5),(2,7),(1,10), 14 (2,7),(2,5),(3,6),(3,11),(2,14)) 15 #_Register_it_under_the_name_"rabbit" 16 getscreen().register_shape("rabbit",rdata) 17 #_ Define_card_suit_shapes 18 d=((0,16),(10,0),(0,-16),(-10,0),(0,16)) 19 h=((0,6),(2,8),(4,9),(8,9),(10,8),(12,6),(13,4), 20 (13,0),(12,-2),(11,-3),(0,-16),(-11,-3),(-12,-2), 21 (-13,0),(-13,-4),(-12,-6),(-10,-8),(-8,-9),(-4,-9), 22 (-2,-8),(0,6)) 23 s=((0,16),(10,4),(12,2),(13,-2),(12,-6),(10,-8), 24 (8,-9),(4,-9),(1,-8),(3,-16),(0,-16),(-3,-16), 25 (-1,-8),(-4,-9),(-8,-9),(-10,-8),(-12,-6),(-13,-2), 26 (-12,-2),(-10,-4),(0,16)) 27 c=((0,16),(4,15),(6,13),(7,10),(7,8),(6,5),(4,3), 28 (1,2),(1,-2),(2,-2),(3,1),(5,3),(7,4),(11,4), 29 (13,3),(15,1),(16,-3),(15,-7),(13,-9),(11,-10), 30 (7,-10),(5,-9),(3,-7),(2,-4),(1,-4),(1,-8),(3,-16), 31 (0,-16),(-3,-16),(-1,-8),(-1,-4),(-2,-4),(-3,-7), 32 (-5,-9),(-7,-10),(-11,-10),(-13,-9),(-15,-7),(-16,-3), 33 (-15,1),(-13,3),(-11,4),(-7,4),(-5,3),(-3,1), 34 (-2,-2),(-1,-2),(-1,2),(-4,3),(-6,5),(-7,8),(-7,10), 35 (-6,13),(-4,15),(0,16)) 36 #_ Register_them_under_the_names_"dia","heart","shade","clover" 37 getscreen().register_shape("dia",d) 38 getscreen().register_shape("heart",h)	

```

39 getscreen().register_shape("spade",s)
40 getscreen().register_shape("clover",c)
41 #
42 # Outline_color_and_fill_color_of_the_generated_turtle_shapes
43 #
44 # The 1st row of shapes contains the 6 shapes that
45 # can be used by default
46 shapes = ["arrow", "turtle", "circle", "square", "triangle", "classic",
47             "rabbit", "dia", "spade", "heart", "clover"]
48 colors = ["black", "green", "black", "black", "black", "black",
49             "red", "red", "black", "red", "black"]
50 colors_fill = ["white", "white", "white", "white", "white", "white",
51                 "white", "red", "black", "red", "black"]
52 #
53 # In the turtle list ttls, generate a turtle with Turtle(), set
54 # the shape and color and then let it walk for a bit.
55 ttls = []
56 for i in range(len(shapes)):
57     ttls.append(Turtle())
58     ttls[i].up()
59     ttls[i].shape(shapes[i])
60     ttls[i].color(colors[i], colors_fill[i])
61     for j in range(i*3):
62         ttls[i].fd(20)
63         ttls[i].left(10)
64 #
65 # Doing a lap together
66 #
67 for i in range(36):
68     for i in range(len(shapes)):
69         ttls[i].fd(20)
70         ttls[i].left(10)

```

Running this program displays the drawings shown below.

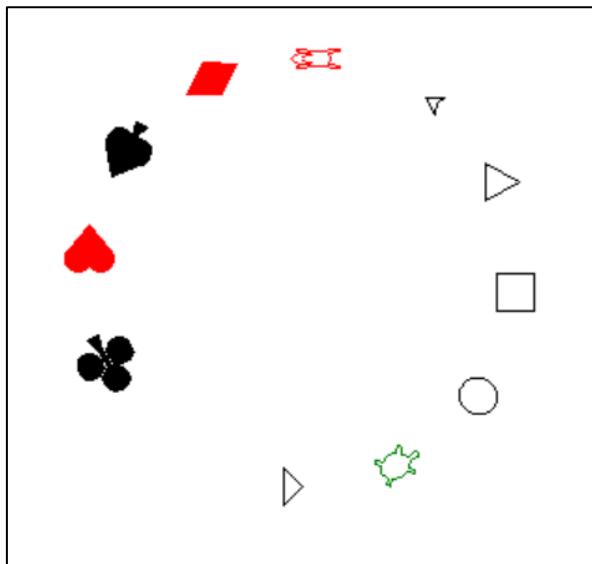


Figure 10-4 Execution result of Program 10-5

10.9 Turtle Demo

Python provides a turtle graphics demo program that can be called from the IDLE menu.

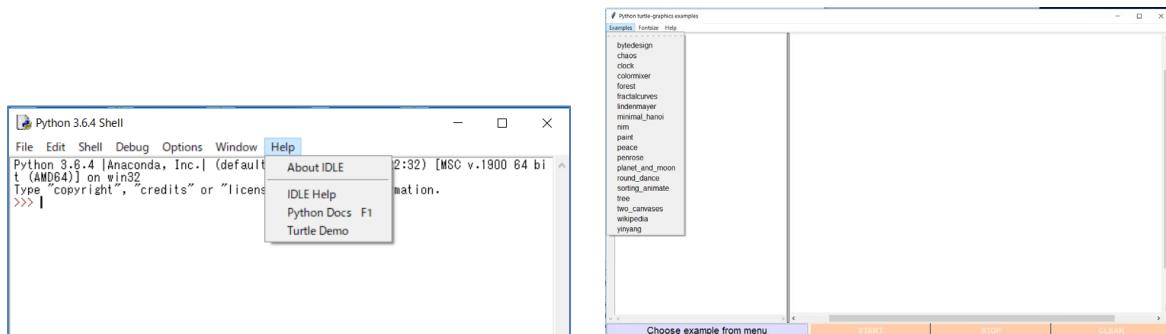


Figure 10-5 How to run the Turtle Demo

10.10 Theme: Creating projects with turtle

To test your skills so far, please create a project using Turtle.

- You will submit the program, screenshots, and your notes.
- The program should be programmed by you.
 - However, it is okay to ask for advice. Please include an acknowledgement of the advice you receive in your notes.
 - Submit your project as an attachment.
- The following information should be included in the memo.
 - Name, affiliation
 - Description of your project
 - The functions of Python and turtle graphics that you have learned.
 - Bibliographic information about any information you referred to, if applicable, and if it is a website, the title, URL and access date of the website
 - If there is someone who helped you, write the name of the person who helped you and a description of the help you received in the acknowledgments.
 - This should be written in Word etc. and submitted as a PDF file.

10.11 How to take a screenshot

- To obtain a screenshot of a specific window in Windows, follow the steps below.
 - ✧ Select the window.
 - ✧ Hold down the ALT key and press the PRTSC key.
If you press only the PRTSC key, a screenshot of the entire screen will be taken.

- ✧ This will copy the screenshot to the clipboard.
- ✧ You can then save the screenshot by pasting the contents of the clipboard into a program that can manipulate images, such as Paint.
- ✧ See [17] for more details about screenshots on a Mac.

Table 10-1 Key Operation to Take a Schreen Shot

		The entire desktop	A specific window	Location of the shot
Windows		Print Screen key	Alt + Print Screen key	Clipboard (with copy)
		Win + Print Screen key	Win + Alt + Print Screen key	Save the file in PNG format in the Picture Screenshot folder/Video Capture folder
Mac		Command + shift + 3	Command + shift + 4 + space	Save to Desktop as PNG

In current Windows 11, a screen shot tool ‘Snipping tool’ is launched with Print Screen key instead of taking the screen shot of the entire desktop.



Figure 10-6 Keys used to take a schreen shot in Windows

References

- [15] Seymour A. Papert: Mindstorms: Children, Computers, And Powerful Ideas, Basic Books (1993)
- [16] 戸塚滝登著: コンピュータ教育の銀河, 晩成書房 (1995, in Japanese)
- [17] Taking a screenshot on a Mac, <https://support.apple.com/ja-jp/HT201361>(accessed May 7, 2021)

Program 10-6 random_turtle.py

Ro	Source code
W	<pre>1 from turtle import * 2 import random 3 # Import random module as you will be using random numbers 4 5 # Variable (flag) to stop execution 6 stop_flag=False 7 8 # Function called when the mouse is clicked; takes x, y parameters 9 # We need this here, but we will not use it 10 # Set the stop_execution flag to True 11 12 def clicked(x,y): 13 global stop_flag 14 stop_flag=True 15 16 # 17 # Specify what to do when the mouse is clicked; 18 # here, call the clicked function. 19 # 20 onscreenclick(clicked) 21 22 speed(0) 23 while(not stop_flag): 24 # Randomly change the orientation in the range of -90 to 90 degrees 25 left(random.randint(-90,90)) 26 forward(10) 27 # If the turtle's position is more than a certain distance from the origin, go back. 28 if position()[0]**2+position()[1]**2>200**2: 29 forward(-10)</pre>

Program 10-7 detour.py

Row	Source code
1	from turtle import *
2	def detour(L):
3	if L < 10:
4	forward(L)
5	else:
6	LL = L/3
7	detour(LL)
8	left(60)
9	detour(LL)
10	right(120)
11	detour(LL)
12	left(60)
13	detour(LL)
14	
15	for i in range(6):
16	detour(100)
17	left(60)

Program 10-8 turtle_tree.py

Row	Source code
1	from turtle import *
2	
3	# Recursively draw a tree
4	def tree(n):
5	# If parameter is less than or equal to 1, go forward 5 steps.
6	if n<=1:
7	forward(5)
8	else:
9	# If the parameter is greater than 1,
10	# move (the trunk) forward according to the value of the parameter
11	forward(5*(1.1**n))
12	# Record the current position and orientation
13	xx=pos()
14	h=heading()
15	# Rotate 30 degrees to the left
16	left(30)
17	# Draw a tree of size n-2 (left branch)
18	tree(n-2)
19	# Raise the pen to stop drawing the trajectory
20	up()
21	# Return to the previously recorded position (top of the trunk)
22	setpos(xx)
23	setheading(h)
24	# Pull the pen down
25	down()
26	# Go 15 degrees to the right
27	right(15)
28	# Draw a tree with size n-1 (right branch)
29	tree(n-1)
30	# Pull pen up and go back
31	up()
32	setpos(xx)
33	setheading(h)
34	# Pull the pen down
35	down()
36	
37	# Use the fastest drawing speed, as it takes a long time
38	speed(0)
39	
40	# Draw a tree of size 12
41	tree(12)

11. Creating a GUI Application with Tkinter (1)

11.1 Learning goals of this chapter

In this chapter, you will create a GUI application using tkinter, and learn:

- The role of frameworks in GUI applications, and learn about event-driven programming.
- The MVC architecture in GUI applications.
- To understand how to define functions in Python by implementing callback functions in tkinter.

11.2 GUIs and event-driven programming

In GUI applications, the user selects and uses various operations using menus and buttons. They also expect the computer to respond appropriately to their actions.

- These user operations are called “**events**.”
- Many GUI applications use a GUI “framework.”
- The framework monitors the mouse and keyboard operations, detects events, and calls the event-handling program set up by the programmer.

In a GUI application that uses a framework, the programmer is mainly responsible for programming the following parts.

- Configuration of the screen where buttons, etc. are placed to be used as a GUI application
- Definition of the processes to be run when an event occurs

This type of programming is called **event-driven programming** because it mainly describes responses to events.

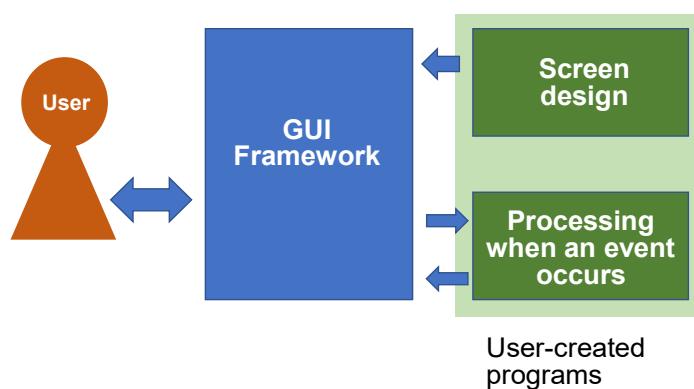


Figure 11-1 Framework for event-driven programming

11.3 Separating the model and user interface

Let's say you want to write a calculator program that handles addition, subtraction, multiplication,

and division. Since addition, subtraction, multiplication, and division are operations on two numbers (binary operations), the user wants to delegate the task to the computer as follows:

- The “first number,” “second number,” and “operation to be performed,” are “set,” then
- the set operation is “applied.”
- The “result of the application” is “obtained”

The words written in blue are “things” that act as the targets of operations such as numbers and operations, and are indicated by “nouns (phrases).” On the other hand, the words written in red are “operations” and are indicated by verbs including verbal nouns. These constitute the “model” of the “calculator” task.

On the other hand, in order for people to interact with this model, you need a user interface that people can operate. The user interface of a calculator application on a personal computer or a smart phone is one example, as well as a Python shell where expressions can be entered using the keyboard. For visually impaired users, interfaces with audio and braille may be required.

If you focus on creating a calculator, you can say that the “model” is shared and only the user interface changes in various ways. In GUI programming, this concept is called an “MVC architecture.” Let’s look over the definitions of M, V, and C below. Reference the column titled “GUI.”

- M: Model - a model to be computed that provides the framework of the application, essentially independent of the GUI.
- V: View - a program that shows the results obtained by the model to the user, which is handled by the GUI.
- C: Control, a program for user operations on the model, which is handled by the GUI.

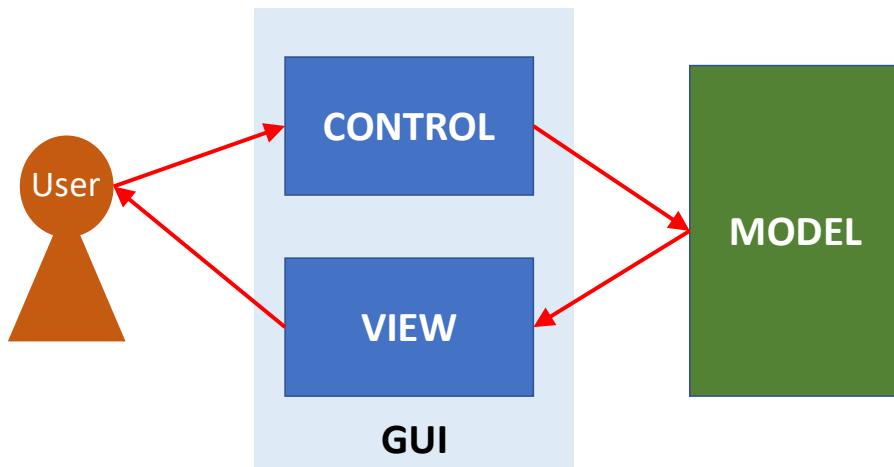


Figure 11-2 Model-View-Control Architecture

11.4 tkinter

There are several basic software and windowing environments for personal computers, such as Windows, macOS, Linux/X-Window. Each of them uses different methods for drawing windows.

Tcl/Tk is a GUI framework that absorbs the differences between these OS and windowing environments so that it can be used across different platforms.

tkinter is a package that makes Tcl/Tk available in Python.

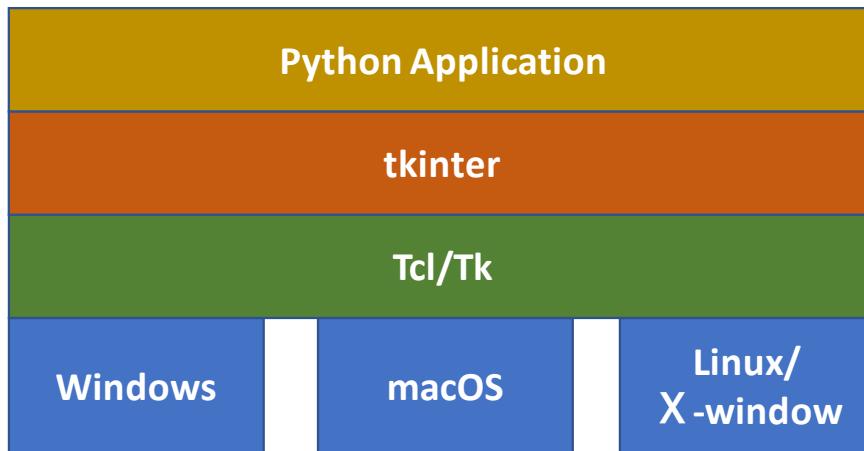


Figure 11-3 Tkinter system configuration

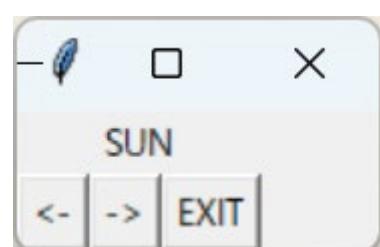
11.4.1 Terms in tkinter

- **Widget:** A generic term for a component such as a button that makes up a GUI.
- **Container:** A receptacle for widgets (groups of widgets).
- **Layout manager/geometry manager:** A mechanism to adjust the geometric arrangement of widgets.
- **Callback function:** A function that is called when a widget is manipulated to perform the necessary processing.

11.5 A simple exercise

We will start with an easy exercise to make sure you understand the framework of programs using tkinter as well as the concepts and terms associated with them. The program below uses the “<-” and “->” buttons like the diagram on the left to scroll through the displayed days of the week. The GUI can be exited by pressing the “EXIT” button.

This is a simple exercise, so please use it to try out various functionalities of tkinter.



Program 11-1 Simple tkinter exercise (tkdemo.py)

Row	Source Code	Notes
1	# Simple tkinter exercise, scroll through the days	
2	# of the week with a button	
3	import tkinter as tk	Import the tkinter module with the name tk.
4	# Number that denotes the days list and current display	dow stands for day of week.
5	dow = ["SUN", "MON", "TUE", "WED", "THU", "FRI", "SAT"]	current_dow is a variable that stores the index of the day that is being displayed.
6	current_dow = 0	current_dow is treated as a global variable,
7		
8	# callback function that moves the day forward	
9	def forward():	
10	global current_dow	
11	current_dow += 1	
12	if current_dow == 7:	
13	current_dow = 0	
14	l_dow["text"] = dow[current_dow]	Update the text attribute of label l_dow.
15		
16	# callback function that moves the day back	
17	def backward():	Everything but lowering current_dow is the same as the forward function.
18	global current_dow	
19	current_dow -= 1	
20	if current_dow == -1:	
21	current_dow = 6	
22	l_dow["text"] = dow[current_dow]	
23	# callback function that terminates tkinter	
24	def fin():	The destroy method of root window is called to terminate.
25	root.destroy()	Generate window as a root with the Tk method.
26	# Window and widget creation, widget layout	Generate Frame as f root as parent, and position via grid() method.
27	root = tk.Tk()	Generate a label that displays the day, position using three columns in 0th row.
28	f = tk.Frame(root)	Specify the call back function with the text attribute and command attribute to generate 3 buttons, position in 1st row
29	f.grid()	Start GUI with the mainloop() method
30	#	Confirm that it terminated
31	l_dow = tk.Label(f, text=dow[current_dow])	
32	l_dow.grid(row=0, column=0, columnspan=3)	
33	#	
34	b_backward = tk.Button(f, text="<", command=backward)	
35	b_forward = tk.Button(f, text=">", command=forward)	
36	b_exit = tk.Button(f, text="EXIT", command=fin)	
37	b_backward.grid(row=1, column=0)	
38	b_forward.grid(row=1, column=1)	
39	b_exit.grid(row=1, column=2)	
40	# Start GUI	
41	print("tkinter started")	
42	root.mainloop()	
43	# Confirm GUI termination	
44	print("tkinter stopped")	

The tkinter program will be structured in the following way.

- It seems to be common to **import the tkinter module** using the name tk. (3rd row)
- **Defining the variables to be used in the program** (5th and 6th row).
- **Definition of the call back function**, description of the behavior when the button is pressed (when an event occurs). (Rows 8 to 25)

- In this exercise, by making current_dow, which is the variable that indicates the display position of the days of the week, into a global variable, we are able to get the two buttons to work properly without messing each other up.
- Changing the text attribute of l_dow that displays the day when the button is pressed. (14th and 22th row)
- In the fin() function, we terminate the GUI by calling the window root's destroy() method. (25th row)
- We have fleshed out the inner workings of the program pretty well now, so next we will **generate and position the windows and widgets that control and display it**.
 - Generate a window using the tk.Tk() method
 - Use the tk.Frame() method to generate a Frame container that has the window root as its parent.
 - Assignment to Frame f window root using the geometry manager grid() method. An argument is not necessary because f is the only thing that it can be assigned to.
 - Generate and position label and button widgets positioned on top of Frame widget f
 - ✧ Generation and assignment of Label widgets that will display characters. In this example, the 0th column to the 3rd column of the 0th row is used for assignment.
 - ✧ Generate and position 3 buttons. The characters that the text attribute displays can specify the callback function that runs when the command attribute's button is pressed.
- At this point, the GUI is ready, so launch the GUI using the mainloop() method from root. Please confirm for yourself that 44th row is not executed until the EXIT button is pressed and the GUI is closed.

The generated window and widget object relationships are showed on Figure

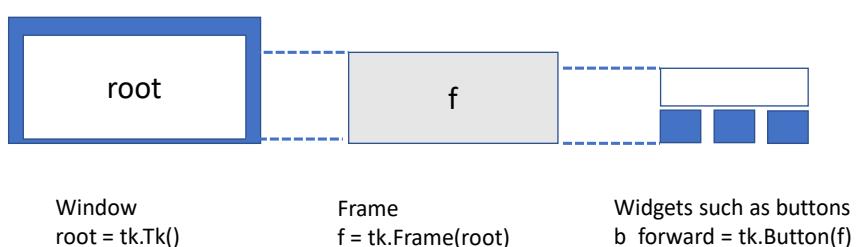


Figure 11-4 Object relationships in tkinter

Also, show the behavior carried out by the widgets, call back functions, and global variables on Figure 11-5 when a button is pressed.

Call Back Functions

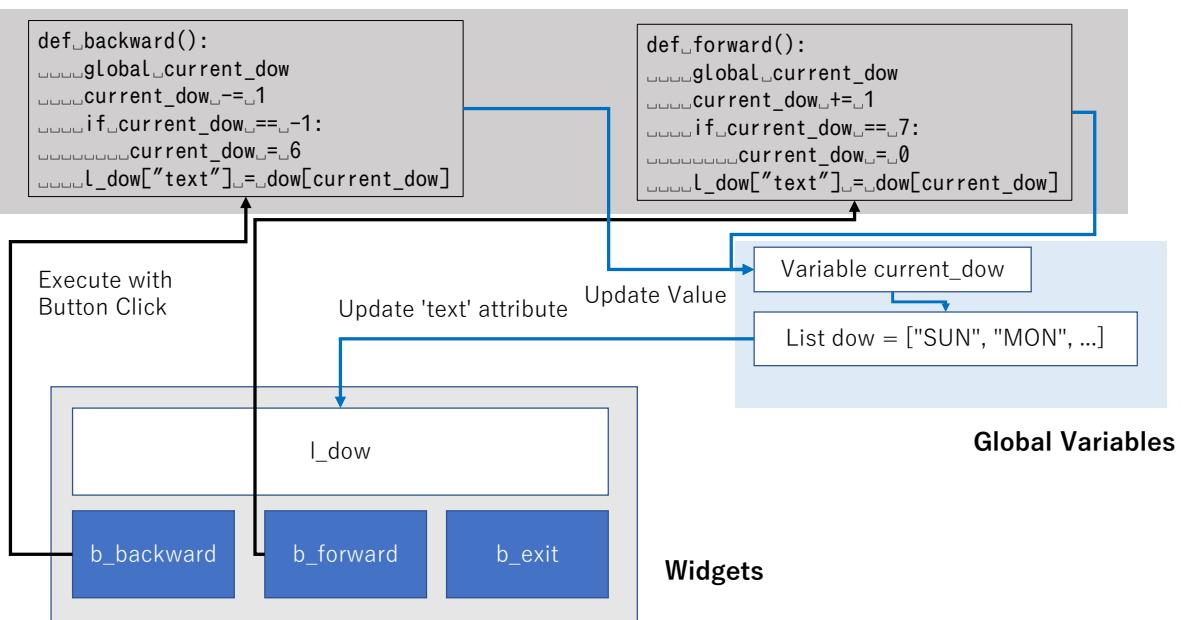


Figure 11-5 Behavior carried out by the widgets, call back functions, and global variables

11.6 tkinter example of calculator (tkdemo_2term.py)

Consider the following addition-only calculator.

- It consists of 10 keys (0-9), 3 buttons (C (clear), + (add), = (calculate)),
- and a single line of character input/output for numerical values.
- The 0 to 9 buttons insert a digit at the least significant digit of the number being entered, just like a calculator. (Multiply the number entered thus far by 10 and add the number of the pressed key to it.)
- C sets the numerical value to 0.
- The + key registers the input number as the first term of a binary operation and then sets the input number to 0 again.
- The = key registers the second input number as the second term of the binary arithmetic operation, executes the addition, prints the result, and zeros the input number.



Program 11-2 is an example implementation of this.

Program 11-2 Calculator for addition only (tkdemo_2term.py)

Row	Source code	Notes
1	import tkinter as tk	
2		
3	# Defines variables for calculation functions and functions for events.	Import tkinter using its short form tk
4		
5	# Model for binary operations	Note that there is no dependency on variables, functions, or GUIs to handle binary operations
6	# Number being entered	
7	current_number = 0	
8	# First number	
9	first_term = 0	
10	# Second number	
11	second_term = 0	
12	# Result	
13	result = 0	
14		
15	def do_plus():	
16	'''calculation when + key was pressed, set the first term and clear the current input'''	
17	global current_number	
18	global first_term	
19		
20	first_term = current_number	
21	current_number = 0	
22		
23	def do_eq():	
24	'''calculation when = key was pressed, set the second term, execute addition, clear the current input'''	
25	global second_term	
26	global result	
27	global current_number	
28	second_term = current_number	
29	result = first_term + second_term	
30	current_number = 0	
31		
32	# Number key callback function	The definition of the widget's callback function starts here
33	def key1():	
34	key(1)	
35		
36	def key2():	
37	key(2)	
38		
39	def key3():	
40	key(3)	
41		
42	def key4():	

	<pre> 43 key(4) 44 45 def key5(): 46 key(5) 47 48 def key6(): 49 key(6) 50 51 def key7(): 52 key(7) 53 54 def key8(): 55 key(8) 56 57 def key9(): 58 key(9) 59 60 def key0(): 61 key(0) 62 63 # Functions for batch processing number keys 64 def key(n): 65 global current_number 66 current_number = current_number * 10 + n 67 show_number(current_number) 68 69 def clear(): 70 global current_number 71 current_number = 0 72 show_number(current_number) 73 74 def plus(): 75 do_plus() 76 show_number(current_number) 77 78 def eq(): 79 do_eq() 80 show_number(result) 81 82 def show_number(num): 83 e.delete(0, tk.END) 84 e.insert(0, str(num)) 85 86 # Create the tkinter screen 87 88 root = tk.Tk() 89 f = tk.Frame(root) 90 f.grid() </pre>	<p>The processing of number keys is the same, only the numbers are different</p> <p>Processing the Clear key</p> <p>Processing the + key</p> <p>Processing the = key</p> <p>Function to display a number entered by the user</p> <p>Create a window with Tk() Create a frame container Assign a frame</p>
--	--	---

<pre> 91 92 #_Create_a_widget 93 94 b1=tk.Button(f,text='1',command=key1) 95 b2=tk.Button(f,text='2',command=key2) 96 b3=tk.Button(f,text='3',command=key3) 97 b4=tk.Button(f,text='4',command=key4) 98 b5=tk.Button(f,text='5',command=key5) 99 b6=tk.Button(f,text='6',command=key6) 100 b7=tk.Button(f,text='7',command=key7) 101 b8=tk.Button(f,text='8',command=key8) 102 b9=tk.Button(f,text='9',command=key9) 103 b0=tk.Button(f,text='0',command=key0) 104 bc=tk.Button(f,text='C',command=clear) 105 bp=tk.Button(f,text='+',command=plus) 106 be=tk.Button(f,text="=",command=eq) 107 108 #_Lay_out_widgets_using_a_grid_geometry_manager 109 110 b1.grid(row=3,column=0) 111 b2.grid(row=3,column=1) 112 b3.grid(row=3,column=2) 113 b4.grid(row=2,column=0) 114 b5.grid(row=2,column=1) 115 b6.grid(row=2,column=2) 116 b7.grid(row=1,column=0) 117 b8.grid(row=1,column=1) 118 b9.grid(row=1,column=2) 119 b0.grid(row=4,column=0) 120 bc.grid(row=1,column=3) 121 be.grid(row=4,column=3) 122 bp.grid(row=2,column=3) 123 124 #_Widget_to_display_numbers 125 e=tk.Entry(f) 126 e.grid(row=0,column=0,columnspan=4) 127 clear() 128 129 #_The_GUI_starts_here 130 root.mainloop() </pre>	<p>Create a button with display text and a callback function</p>
	<p>Assign the button to the frame by specifying its position with grid</p>
	<p>Create an Entry widget for text input to display numeric values, and define its horizontal size</p>
	<p>Go to GUI processing with the mainloop method</p>

11.7 Basic structure of a program using tkinter

Importing the module

```
import tkinter as tk # Import tkinter as the shorter custom name of tk
```

Define the callback function

```
def key1():
```

Contents of key1

Create the window

```
root = tk.Tk()
```

Create and allocate a frame. A frame is a kind of container that stores widgets inside it.

```
f = tk.Frame(root)      # Create a frame with root as its parent,
```

```
f.grid()                # and allocate it to a location with grid()
```

Creating a widget (button)

```
b1 = tk.Button(f, text='1', command=key1)
```

Create a button with f as the parent. The text to display is '1', command to execute is key1

1. Create a widget (entry, to display text)

```
e = tk.Entry(f)
```

2. Specify the layout

```
b1.grid(row=3, column=0)
```

3. Run the GUI

```
root.mainloop()
```

11.8 Layout on a grid

A widget in tkinter can be assigned to a window or container after specifying a layout manager to manage the layout. There are several layout managers, but one of the simplest is grid, which provides a grid for positioning widgets. It can be used as follows.

- Define a grid layout by specifying its position

```
b1.grid(row=3, column=0)
```

- It is also possible to specify how many columns there will be

```
e.grid(row=0, column=0, columnspan=4)
```

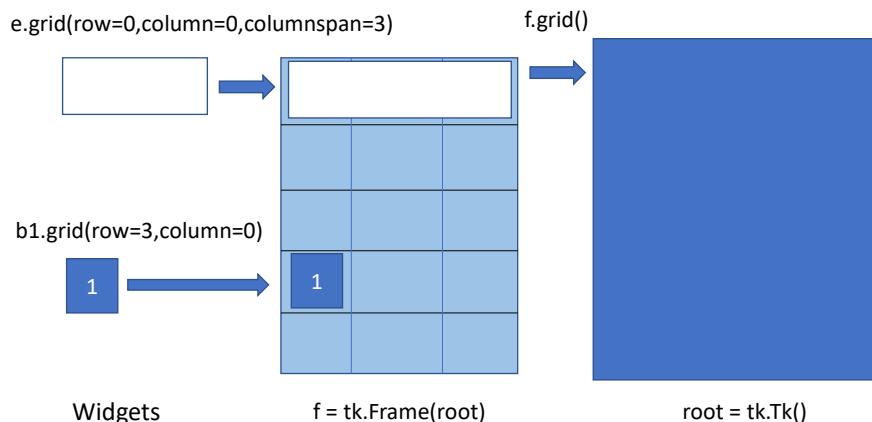


Figure 11-6 Layout with grid

11.9 Writing a callback function using a lambda (λ) notation

In the previous example, the contents of the functions `key0()` to `key9()` are calls to the function `key()` with different arguments. In the definition of the widget, the `command=key1` argument on the right side of

```
b1 = tk.Button(f, text='1', command=key1)
```

must be a "function object," and if you write

```
b1 = tk.Button(f, text='1', command=key(1)) # This is wrong
```

then the argument of the `key()` function will be set to 1, the function is called, and into the command, the return value is assigned. If you designate an argument of 1 to the `key()` function, it will not be called as a callback function. On the other hand, the function `key1()` is a dedicated callback function for button `b1`, and is not used for any other purpose. In this sense, it would be convenient to directly link the definition of the function `key1()` with the specification of the callback function for button `b1`, eliminating the need for the name `key1`.

Python uses the lambda notation¹ to achieve this, where a function is defined and assigned to a variable without naming it on the fly. In the example of `b1`,

```
b1 = tk.Button(f, text='1', command=lambda:key1)
```

The `key(1)` following `lambda:` is the content of the ad hoc function definition, which is essentially the same as the `key1()` function.

¹ The name comes from a theoretical model called lambda calculus, which is used in computer science.

Program 11-3 Setting up a callback function with arguments using a lambda notation (tkdemo_2term_lambda.py)

Row	Source code	Notes
1	import tkinter as tk	
2		
3	# Defines variables for calculation functions and those for events.	Import tkinter using its short form tk
4	# Model for binary operations	
5	# Number being entered	
6	current_number = 0	
7	# First number	
8	first_term = 0	
9	# Second number	
10	second_term = 0	
11	# Result	
12	result = 0	
13		
14	def do_plus():	
15	"""calculation when + key was pressed, set the first term and clear the current input""	
16	global current_number	
17	global first_term	
18		
19	first_term = current_number	
20	current_number = 0	
21		
22	def do_eq():	
23	"""calculation when = key was pressed, set the second term, execute addition, clear the current input""	
24	global second_term	
25	global second_term	
26	global result	
27	global current_number	
28	second_term = current_number	
29	result = first_term + second_term	
30	current_number = 0	
31		
32	# Functions for batch processing number keys	
33	def key(n):	
34	global current_number	
35	current_number = current_number * 10 + n	
36	show_number(current_number)	
37		
38	def clear():	
39	global current_number	
40	current_number = 0	
41	show_number(current_number)	

```
42
43     def plus():
44         do_plus()
45         show_number(current_number)
46
47     def eq():
48         do_eq()
49         show_number(result)
50
51     def show_number(num):
52         e.delete(0,tk.END)
53         e.insert(0,str(num))
54
55 #Create the tkinter screen
56
57 root=tk.Tk()
58 f=tk.Frame(root)
59 f.grid()
60
61 #Create a widget
62
63 b1=tk.Button(f,text='1',command=lambda:key(1))
64 b2=tk.Button(f,text='2',command=lambda:key(2))
65 b3=tk.Button(f,text='3',command=lambda:key(3))
66 b4=tk.Button(f,text='4',command=lambda:key(4))
67 b5=tk.Button(f,text='5',command=lambda:key(5))
68 b6=tk.Button(f,text='6',command=lambda:key(6))
69 b7=tk.Button(f,text='7',command=lambda:key(7))
70 b8=tk.Button(f,text='8',command=lambda:key(8))
71 b9=tk.Button(f,text='9',command=lambda:key(9))
72 b0=tk.Button(f,text='0',command=lambda:key(0))
73 bc=tk.Button(f,text='C',command=clear)
74 bp=tk.Button(f,text='+',command=plus)
75 be=tk.Button(f,text="=",command=eq)
76
77 #Layout widgets using a grid geometry manager
78
79 b1.grid(row=3,column=0)
80 b2.grid(row=3,column=1)
81 b3.grid(row=3,column=2)
82 b4.grid(row=2,column=0)
83 b5.grid(row=2,column=1)
84 b6.grid(row=2,column=2)
85 b7.grid(row=1,column=0)
86 b8.grid(row=1,column=1)
87 b9.grid(row=1,column=2)
88 b0.grid(row=4,column=0)
89 bc.grid(row=1,column=3)
```

```

90 be.grid(row=4,column=3)
91 bp.grid(row=2,column=3)
92
93 #_Widget_to_display_numbers
94 e_=tk.Entry(f)
95 e.grid(row=0,column=0,columnspan=4)
96 clear()
97
98 #_The_GUI_starts_here
99 root.mainloop()

```

11.10 Configuring the appearance of a widget

There are several ways to configure the color, size, font, etc. of a widget, such as a button.

11.10.1 How to set an argument when creating the widget

You can specify arguments when generating the widget. It is convenient to use keyword arguments.

- font=('Helvetica', 14) Text font and size
- width=2 The size of the widget
(For buttons, the number of characters)
- bg = '#ffffc0' Background color, two hexadecimal digits each in
RGB 00 is darker, ff is lighter

Note that bg does not currently change the color on the Mac, so if you set the argument highlightbackground instead of bg, the color of the button itself will not change, but the color around the button will. Please substitute highlightbackground in for bg if you are doing this exercise on a Mac.

Table 11-1 Specifying colors with tkinter

Notation	Red	Green	Blue	Color
'# ffffff '	ff	ff	ff	White
'# 000000 '	00	00	00	Black
'# ff0000 '	ff	00	00	Red
'# 00ff00 '	00	ff	00	Green
'# 0000ff '	00	00	ff	Blue

11.10.2 Configuring the Appearance of a Generated Widget (Part 1)

To change the appearance of a generated widget while it is running, use the `configure()` method of the widget. The arguments are allocated in the same way as the keyword arguments are at the time of generation. For example, suppose `b` is a button widget as follows:

```
b.configure(size=2)
```

To reference the current value, call the `cget()` method with the attribute as an argument. Note that the attribute is given as a string.

```
b.cget("size")
```

11.10.3 Configuring the Appearance of the Generated Widget (Part 2)

The appearance of the widget can also be set and referenced in the following way. Note that the settings in square brackets must be a string (enclosed by quotation marks, etc.). Settings are performed by substitution.

```
b["size"] =2  
print(b["size"])
```

Exercise 11-1 Create an Addition Calculator with Tkinter

Write a program like Program 11-2 or Program 11-3 and see how it works.

Exercise 11-2 Configuring the appearance of a widget

- Set the font size of the addition calculator and the color of the widget as follows. Set the background color to '#ffffc0' (light yellow) for the frame, white for numeric keys, red for clear keys, and green for + and = keys.
- The size of the button should be 2 (the length in characters).
- The font and size of the button and entry should be ('Helvetica', 14).

Exercise 11-3 Extending the Calculator to Four Arithmetic Operations (Skill Test)

Extend the addition calculator so that it can perform the four primary arithmetic operations. However, keep the following in mind.

- You must consider the placement of the buttons.
- For division, since a divide by zero error may occur, when the second term is zero, either do nothing or display an error.
- Omit the decimal point for division. The operator for finding the integer quotient in Python is “//.”

Hint: The program needs to be extended in the following two ways.

- Add a button widget to specify the four arithmetic operations.
(This should not be too difficult.)
- Set up a callback function for when the arithmetic operator button or the “=” button is pressed.

Consider the following hints.

- In a calculator, when an operation key such as + is pressed, the operation is not performed; it is performed when the = key is pressed. Thus, when an arithmetic key (for addition, subtraction, multiplication, or division) is pressed, the calculator stores the operation to be performed in a variable until it is executed. For example, you could set up a variable called “operation” and set it to 1 for addition, 2 for subtraction, 3 for multiplication, 4 for division.
- When the = key is pressed, you need to change the operation that is actually performed to match the stored operation. For example, your code may look like this:

```
if operation == 1:
    Block that performs addition
elif operation == 2:
    Block that performs subtraction
elif operation == 3:
    Block that performs multiplication
else:
    Block that performs division
```

Exercise 11-4 Management of Widgets with List (Skill Test)

In Program 11-2 and Program 11-3, we use many Button widgets. Try to manage them by using these objects as members of a list. With this list, try to rewrite the program using 'for' statement.

Note: we use a lambda expression in Program 11-3 (for example, command=lambda:i:key(1)). Here, the argument of function key(1) is given as a constant, but with this expression, we can't use a variables (for example, i) whose value should be evaluated at the definition of the lambda expression. It can be written using lambda expression with an argument having a default value like the following:

```
command=lambda x = i:key(x)
```

Exercise 11-5 Differences with an actual calculator

Look for differences in behavior between your program and an actual calculator (or calculator application). For example, what happens when you press an arithmetic key such as + instead of =? You will find that actual calculator products are well designed.

11.11 How to close tkinter

In an application using tkinter, calling mainloop() will result in an infinite loop that waits for user action and then calls the callback function. Methods of closing tkinter other than exiting with the exit

button of the window are as follows.

- To escape from mainloop(), call the quit() or destroy() method of the object created by tk.Tk() (e.g., root) in a given callback function. The difference in the behavior of these methods is as follows:
 - quit(): The program exits the loop, but the window or widgets remain.
 - destroy(): exits the loop and removes the window or widgets altogether.

11.12 How to extend the Frame class

In the previous program, Frame and widgets such as the Button widget were configured separately. However, in practical examples of tkinter, Frame is often implemented as an extended class and widgets are generated during its initialization. In this section, we show an example of this. For more information about classes, please refer to the explanation in a later chapter.

**Program 11-4 How to extend the Frame class in tkinter
(tkdemo-2term_frame_extention.py)**

Row	Source code	Notes
1	import tkinter as tk	
2		
3	#_Defines_variables_for_calculation_functions_and_those_for_events	
4	.	
5	#_Example_using_Frame_subclasses	
6	#_Model_for_binary_operations	
7	#_Number_being_entered	
8	current_number_=0	
9	#_First_number	
10	first_term_=0	
11	#_Second_number	
12	second_term_=0	
13	#_Result	
14	result_=0	
15		
16	def do_plus():	
17	"calculation_when+_key_was_pressed,_set_the_first_term_and_clear_the_current_input"	
18	global current_number	
19	global first_term	
20	first_term_=current_number	
21	current_number_=0	
22		
23	def do_eq():	
24	"calculation_when_=key_was_pressed,_set_the_second_term,_executeaddition,_clear_the_current_input"	

```
25     global_second_term
26     global_result
27     global_current_number
28     second_term_=current_number
29     result_=first_term_+second_term
30     current_number_=0
31 #
32 # Create a class called MyFrame that inherits from tk.Frame
33 # Then you can add widgets and callback functions (methods) in __init__,
34 # Which is the standard way of using tkinter
35 #
36 class MyFrame(tk.Frame):
37 #
38     #__init__ is the initialization method used to create class objects;
39     # It has two underscores on each side
40     def __init__(self, master_=None):
41         super().__init__(master)
42     # Create a widget that will not be referenced later (with local variables)
43         b1_=tk.Button(self, text='1', command=lambda:self.key(1))
44         b2_=tk.Button(self, text='2', command=lambda:self.key(2))
45         b3_=tk.Button(self, text='3', command=lambda:self.key(3))
46         b4_=tk.Button(self, text='4', command=lambda:self.key(4))
47         b5_=tk.Button(self, text='5', command=lambda:self.key(5))
48         b6_=tk.Button(self, text='6', command=lambda:self.key(6))
49         b7_=tk.Button(self, text='7', command=lambda:self.key(7))
50         b8_=tk.Button(self, text='8', command=lambda:self.key(8))
51         b9_=tk.Button(self, text='9', command=lambda:self.key(9))
52         b0_=tk.Button(self, text='0', command=lambda:self.key(0))
53         bc_=tk.Button(self, text='C', command=self.clear)
54         bp_=tk.Button(self, text='+', command=self.plus)
55         be_=tk.Button(self, text="=", command=self.eq)
56
57     # Lay out widgets using a grid geometry manager
58         b1_.grid(row=3, column=0)
59         b2_.grid(row=3, column=1)
60         b3_.grid(row=3, column=2)
61         b4_.grid(row=2, column=0)
62         b5_.grid(row=2, column=1)
63         b6_.grid(row=2, column=2)
64         b7_.grid(row=1, column=0)
65         b8_.grid(row=1, column=1)
66         b9_.grid(row=1, column=2)
67         b0_.grid(row=4, column=0)
68         bc_.grid(row=1, column=3)
69         be_.grid(row=4, column=3)
70         bp_.grid(row=2, column=3)
```

```
71
72 # Widgets and class objects that display numbers that will
73 # be referenced by other methods are created as an instance
74 # variable with the "self." prefix
75     self.e=tk.Entry(self)
76     self.e.grid(row=0,column=0,columnspan=4)
77 # When defining a class,
78 # The first parameter of a method is "self."
79 # Inside of a class, the class object variable and method also
80 # reference "self"
81     def key(self,n):
82         global current_number
83         current_number=current_number*10+n
84         self.show_number(current_number)
85
86     def clear(self):
87         global current_number
88         current_number=0
89         self.show_number(current_number)
90
91     def plus(self):
92         do_plus()
93         self.show_number(current_number)
94
95     def eq(self):
96         do_eq()
97         self.show_number(result)
98
99     def show_number(self,num):
100        self.e.delete(0,tk.END)
101        self.e.insert(0,str(num))
102
103 #
104 # Main program from here
105 #
106 root=tk.Tk()
107 f = MyFrame(root)
108 f.pack()
109 f.mainloop()
```

Use the
extended
class. pack()
is a geometry
manager.

11.13 Utilizing images with tkinter

11.13.1 Card images

In this section, we will make use of the exercise that displays images of cards. For the images, we will use the card images that have been published at the site below.

<https://www.kenney.nl/assets/boardgame-pack>

It is worth noting that the terms of use are as seen below.

License: (CC0 1.0 Universal) You're free to use these game assets in any project, personal or commercial. There's no need to ask permission before using these. Giving attribution is not required, but is greatly appreciated!

In the package that one downloads, one will find image data in the form of PNG files within the Cards folder found inside the PNG folder. The image size (number of pixels) is 140 x 190.

11.13.2 Handling images with tkinter

Here we will make use of tkinter's PhotoImage class. The image formats supported by this class are PGM, PPM, GIF, and PNG (Tkinter version 8.6 and on). The well-known JPEG image format cannot be used as-is. To use it, one would need to convert to a different format in advance or concurrently use a different module for image handling.

11.13.3 Program that displays card images

Create a folder called Cards within the folder where this program is saved and store the card images inside it.

As seen in Program 11-5 below,

- First, create a list of the image filenames and store it in cardImages,
- Then create a PhotoImage class object list that has read the image files and assign it to cardImageWidgets.
- After this, we convert the image attributes of the labels for displaying images using the call back functions “back” and “forward.”

Program 11-5 Program that displays card images: tkdemo-show_cards.py

Row	Source Code	Notes
1	# Show Card Images with tkinter	
2	import tkinter as tk	
3		
4	# Components that make up card filenames	
5	backs = ["blue", "green", "red"]	
6	suits = ["Clubs", "Diamonds", "Hearts", "Spades"]	

```

7 ranks = ["A", "2", "3", "4", "5", "6", "7",
8           "8", "9", "10", "J", "Q", "K"]
9 joker = ["Joker"]
10
11 # List that stores card filenames
12 cardImages = []
13 # Card reverse image name
14 for b in backs:
15     for i in range(1,6):
16         card = "cardBack_" + b + str(i) + ".png"
17         cardImages.append(card)
18 # Card front image name
19 for s in suits:
20     for r in ranks:
21         card = "card" + s + r + ".png"
22         cardImages.append(card)
23 # Joker image name
24 cardImages.append("card" + joker[0] + ".png")
25
26 root = tk.Tk()
27
28 # Read the image files in order and create a list of
29 # PhotoImage class objects
30 cardImageWidgets = []
31 for i in cardImages:
32     image = tk.PhotoImage(file="cards/" + i)
33     cardImageWidgets.append(image)
34
35 # Index to access image
36 cardIndex = 0
37
38 def back():
39     'callback function that returns to previous image'
40     global cardIndex
41     cardIndex -= 1
42     if cardIndex < 0:
43         cardIndex = len(cardImageWidgets) - 1
44     # Convert label image attribute
45     l["image"] = cardImageWidgets[cardIndex]
46
47 def forward():
48     'callback function that returns to next image'
49     global cardIndex
50     cardIndex += 1
51     if cardIndex >= len(cardImageWidgets):
52         cardIndex = 0
53     l["image"] = cardImageWidgets[cardIndex]
54
55 f = tk.Frame(root)
56 f.pack()
57 # "Return" button and "Next" button
58 bb = tk.Button(f, text "<", command=back)
59 bf = tk.Button(f, text ">", command=forward)

```

Generate image filenames in order.

Specify a pass to the file, read the image file, and generate a PhotoImage class object.

Two callback functions

Main program starts here

<pre> 60 #Label widget that displays card images 61 L=tk.Label(f, text="card") 62 bb.grid(row=0, column=0) 63 L.grid(row=0, column=1) 64 bf.grid(row=0, column=2) 65 #Set the first image 66 L["image"] = cardImageWidgets[cardIndex] 67 68 root.mainloop() </pre>	<p>Create and position the Label widget that displays the forward and backward buttons and images.</p> <p>Set the first image</p>
---	---

Running the program results in the display shown below (examples of a few cards are shown).

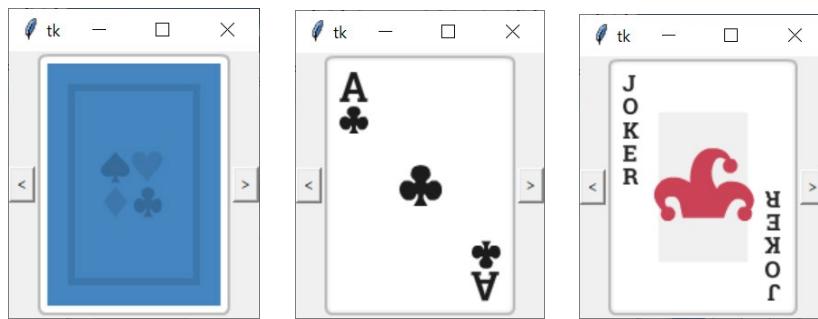


Figure 11-7 Execution of Program 11-5

References

There are many resources on the internet explaining how to use Tkinter. The use of tkinter is slightly different between Python 2 and Python 3. For example, the module to import is Tkinter in Python 2, while it is tkinter in Python 3. Please be careful when referring to articles online.

- [18] Tkinter 8.5 reference: a GUI for Python
<https://infohost.nmt.edu/tcc/help/pubs/tkinter/web/index.html>

12. Creating a GUI Application with Tkinter (2)

12.1 Learning goals of this chapter

In this chapter, you will learn the following skills by creating an analog clock with tkinter:

- How to use autonomous programs such as animations together with a GUI, and
- How to draw graphics using the Canvas widget.

12.2 Conflicts between autonomous programs and GUIs

GUI frameworks such as tkinter observe user operations and delegate processing to a set callback function when an event such as a mouse click occurs. At that time, the callback function is expected to terminate promptly. It waits for the callback function to finish, then goes back to observing, waiting for an event to occur.

At the same time, if the program itself operates continuously (as is the case with an animation) and if the callback function is then called, the observation of events will stop.

In tkinter, there is a method called after that executes the specified callback function after a given period of time to meet both of these needs. Using the after method allows tkinter to register the process after the specified time and terminate the callback function so that the GUI event observation loop is not stopped for a long period of time.

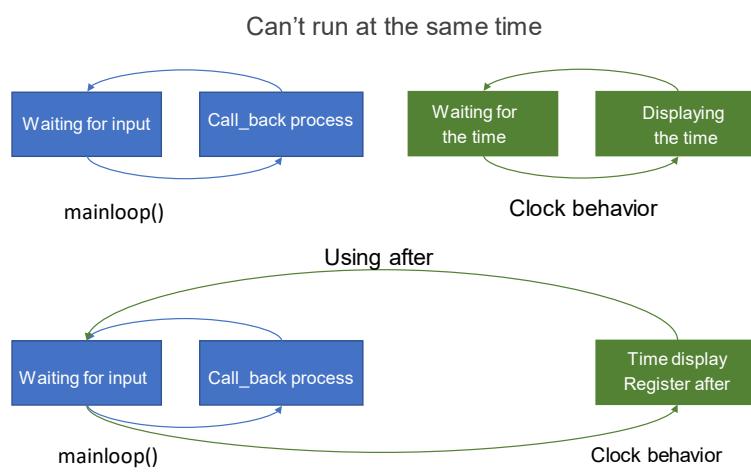


Figure 12-1 Use of 'after' in tkinter

As a caveat, note that this way of doing things is not suitable for applications that require a lot of computation time, such as simulations. You need to look into the use of libraries and concepts such as threads to run programs in parallel.

12.3 Analog clock program using tkinter

In this section, you will create an analog clock as shown in Figure 12-2. It displays the hour, minute,

and second hands, and the date display can be turned on and off with a button. Refer to Figure 12-3 for calculating the position of the clock hands.

The following program is implemented by extending the Frame class. Some lines are longer than others; in the list below, the lines without numbers are a part of long single lines that have had the text wrapped onto a new line. Please be careful when you type this code out.



Figure 12-2 The analog clock you will create

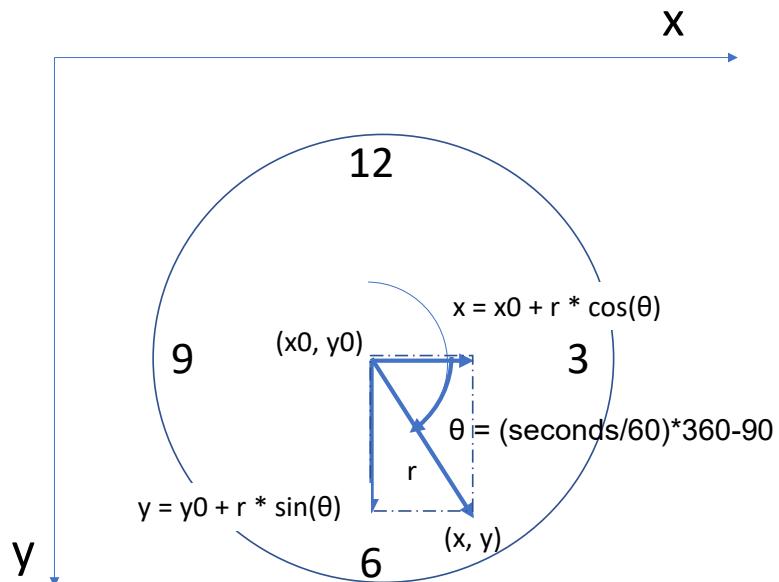


Figure 12-3 Calculation of the position of the hands of the clock

12.3.1 Source code

The program is a bit complicated, so at first, we will look at the code without the button to turn on/off the date display. The code with the button added is shown further below.

**Program 12-1 Analog clock with tkinter (without a date button,
tkdemo_simple_clock.py)**

Row	Source code	Notes
1	#	
2	#_Analog_clock_with_no_date_button_using_tkinter_canvas	
3	#	
4	import_tkinter_as_tk	Import time to handle time
5	import_math	
6	import_time	
7	#	
8	#_Extend_the_Frame_class	
9	#	
10	class_MyFrame(tk.Frame):	Two underscores on each side
11	def__init__(self, master=None):	
12	super().__init__(master)	
13	#	
14	#_Create_a_canvas	
15	#	
16	self.size=200	Widget for drawing
17	self.clock=tk.Canvas(self, width=self.size, height=self.size, background="white")	
18	self.clock.grid(row=0, column=0)	
19	#	
20	#_Draw_the_dial	
21	#	
22	self.font_size=int(self.size/15)	
23	for number in range(1,12+1):	
24	x=self.size/2+math.cos(math.radians(number*360/12-90))*self.size/2*0.85	
25	y=self.size/2+math.sin(math.radians(number*360/12-90))*self.size/2*0.85	
26	self.clock.create_text(x,y, text=str(number), fill="black", font=(" ", 14))	
27	#	
28	#_Create_instance_variables_to_check_for_the_passage_of_time	
29	#	
30	self.sec=time.localtime().tm_sec	
31	self.min=time.localtime().tm_min	
32		

```

33     self.hour = time.localtime().tm_hour
34     #
35     # Draw a dynamic display
36     #
37     def display(self):
38         #
39         # Draw the second hand
40         #
41         self.sec = time.localtime().tm_sec
42         angle = math.radians(self.sec*360/60 - 90)
43         x0 = self.size/2 - math.cos(angle)*self.size/2*0.1
44         y0 = self.size/2 - math.sin(angle)*self.size/2*0.1
45         x = self.size/2 + math.cos(angle)*self.size/2*0.75
46         y = self.size/2 + math.sin(angle)*self.size/2*0.75
47         #
48         # Search for the previous drawing using its tag, delete it, then redraw the new line
49         #
50         self.clock.delete("SEC")
51         self.clock.create_line(x0,y0,x,y, width=1, fill="red", tag="SEC")
52         #
53         # Draw the minute and hour hands, and make the hour hand move slightly every minute
54         #
55         x0 = self.size/2
56         y0 = self.size/2
57         self.min = time.localtime().tm_min
58         angle = math.radians(self.min*360/60 - 90)
59         x = self.size/2 + math.cos(angle)*self.size/2*0.65
60         y = self.size/2 + math.sin(angle)*self.size/2*0.65
61         self.clock.delete("MIN")
62         self.clock.create_line(x0,y0,x,y, width=3, fill="blue", tag="MIN")
63
64         self.hour = time.localtime().tm_hour
65         x0 = self.size/2
66         y0 = self.size/2
67         angle = math.radians((self.hour%12+self.min/60)*360/12 - 90)
68         x = self.size/2 + math.cos(angle)*self.size/2*0.55
69         y = self.size/2 + math.sin(angle)*self.size/2*0.55
70         self.clock.delete("HOUR")
71         self.clock.create_line(x0,y0,x,y, width=3, fill="green", tag="HOUR")
72         #
73         # Draw the date
74         #

```

75	<code>x = self.size/2</code>	
76	<code>y = self.size/2 + 20</code>	
77	<code>text = time.strftime('%Y/%m/%d %H:%M:%S')</code>	
78	<code>self.clock.delete("TIME")</code>	
79	<code>self.clock.create_text(x, y, text=text, font="", 12)</code>	
80	<code>, fill="black", tag="TIME")</code>	
81	<code>#</code>	
82	<code># Call again in 100 milliseconds</code>	
83	<code>#</code>	
84	<code>self.after(100, self.display)</code>	
85	<code>root = tk.Tk()</code>	Main program starts here
86	<code>f = MyFrame(root)</code>	
87	<code>f.pack()</code>	
88	<code>f.display()</code>	Call display first
89	<code>root.mainloop()</code>	

Program 12-2 Analog clock with tkinter

(with a date button, `tkdemo_clock_with_button.py`)

Row	Source code	Notes
1	<code>#</code>	
2	<code>#_Analog_clock_with_a_date_button_using_tkinter_canvas</code>	
3	<code>#</code>	
4	<code>import tkinter as tk</code>	
5	<code>import math</code>	
6	<code>import time</code>	
7	<code>#</code>	
8	<code>#_Extend_the_Frame_class</code>	Import time to handle time
9	<code>#</code>	
10	<code>class MyFrame(tk.Frame):</code>	
11	<code> def __init__(self, master=None):</code>	
12	<code> super().__init__(master)</code>	
13	<code> #</code>	
14	<code> #_Create_a_canvas</code>	
15	<code>#</code>	
16	<code> self.size = 200</code>	Widget for drawing
17	<code> self.clock = tk.Canvas(self, width=self.size, height=self.size, background="white")</code>	
18	<code> self.clock.grid(row=0, column=0)</code>	
19	<code> #</code>	
20	<code> #_Draw_the_dial</code>	
21	<code>#</code>	
22	<code> self.font_size = int(self.size/15)</code>	
23		

```

24     for number in range(1,12+1):
25         x = self.size/2+math.cos(math.radians(number*
360/12-90))*self.size/2*0.85
26         y = self.size/2+math.sin(math.radians(number*
360/12-90))*self.size/2*0.85
27         self.clock.create_text(x,y,text=str(number),fill=
28             "black",font=(" ",14))
29     #
30     # Create a button to toggle the date display on/off
31     #
32     self.b=tk.Button(self, text="Show Date", font=(" "
33         ,14), command=self.toggle)
34     self.b.grid(row=1, column=0)
35     #
36     self.sec=time.localtime().tm_sec
37     self.min=time.localtime().tm_min
38     self.hour=time.localtime().tm_hour
39     self.show_date=False
40
41     #
42     # Callback when the button is pressed
43     #
44     def toggle(self):
45         if self.show_date:
46             self.b.configure(text="Show Date")
47         else:
48             self.b.configure(text="Hide Date")
49         self.show_date=not self.show_date
50
51     #
52     # Draw a dynamic display
53     #
54     def display(self):
55         #
56         # Draw the second hand
57         #
58         self.sec=time.localtime().tm_sec
59         angle=math.radians(self.sec*360/60-90)
60         x0=self.size/2-math.cos(angle)*self.size/2*0.1
61         y0=self.size/2-math.sin(angle)*self.size/2*0.1
62         x=self.size/2+math.cos(angle)*self.size/2*0.75
63         y=self.size/2+math.sin(angle)*self.size/2*0.75
64         #
65         # Search for the previous drawing using its tag, delete it, then redraw the new line

```

Is the date displayed?
 Change the button text
 Invert whether or not the date is shown

```

66      #
67      self.clock.delete("SEC")
68      self.clock.create_line(x0,y0,x,y, width=1, fill="red", tag="SEC")
69      #
70      # Draw the minute and hour hands, and make the hour
71      # hand move slightly every minute
72      #
73      self.min = time.localtime().tm_min
74      x0 = self.size/2
75      y0 = self.size/2
76      angle = math.radians(self.min*360/60 - 90)
77      x = self.size/2 + math.cos(angle)*self.size/2*0.65
78      y = self.size/2 + math.sin(angle)*self.size/2*0.65
79      self.clock.delete("MIN")
80      self.clock.create_line(x0,y0,x,y, width=3, fill="blue", tag="MIN")
81      self.hour = time.localtime().tm_hour
82      x0 = self.size/2
83      y0 = self.size/2
84      angle = math.radians((self.hour%12+ self.min/60)*360/12 - 90)
85      x = self.size/2 + math.cos(angle)*self.size/2*0.55
86      y = self.size/2 + math.sin(angle)*self.size/2*0.55
87      self.clock.delete("HOUR")
88      self.clock.create_line(x0,y0,x,y, width=3, fill="green", tag="HOUR")
89      #
90      # Draw the date
91      #
92      x = self.size/2
93      y = self.size/2 + 20
94      text = time.strftime('%Y/%m/%d %H:%M:%S')
95      self.clock.delete("TIME")
96      if self.show_date:
97          self.clock.create_text(x,y, text=text, font=("Arial", 12), fill="black", tag="TIME")
98      #
99      # Call again in 100 milliseconds
100     #
101    self.after(100, self.display)
102
103 root = tk.Tk()
104 f = MyFrame(root)
105 f.pack()
106 f.display()
107 root.mainloop()

```

Draw only when
the date is
displayed

Main program
starts here

12.3.2 Key points of this program

- You will need to import modules other than tkinter, including the time module, which is imported to handle time, and the math module, which is imported to use trigonometric functions.
- This program defines the MyFrame class, which is an extension of Frame, then creates widgets, assigns them, and defines callback functions within it.
 - The `__init__()` method of the MyFrame class is automatically called when the class object is created. In this method, the necessary widgets are created. There are two underscores on each side of the method name.
 - ✧ The Canvas widget is created for drawing
 - ✧ The dial is drawn by calling the `create_text()` method of the Canvas widget.
 - ✧ A button is created to toggle the display of the time in text. (Only for the code that includes the button)
 - ✧ Instance variables are allocated for time elapsing, display switching, etc., and set the values using the seconds, minutes, hours, etc., in the `time.localtime()` function.
 - A callback function is defined for when the button is pressed. The `b.configure()` method is called to switch the text displayed on the button (`b`), and set the variable representing the state. (Only in the code with the button)
 - Method to draw the clock face:
 - ✧ When using Canvas to draw, you can attach a “tag” to the drawn object, so that you can delete it later. First you will need to delete the old drawing (clock hand).
 - ✧ The coordinates of the clock hands are calculated from the time using a trigonometric function, and drawn using the `create_line()` method.
 - ✧ At the end of this method, the `after` method is set to make this method call itself 100 milliseconds later to continuously draw the clock.
- Finally, there is the main program. The program creates a window with the `Tk()` method, creates a MyFrame class object, draws the first instance of the clock with `f.display()`, and then passes control of the program to tkinter with `mainloop()`.

Exercise 12-1 Reviewing the methods to be used

List the methods of the time module, math module, and tkinter Canvas class that are called in this program, and look over these methods in detail in the Python online documentation.

Exercise 12-2 Modifying the analog clock

Make the following modifications to the analog clock program.

1. For the date display, have it display the date and the time using a.m. and p.m. instead of just the date and time.

2. Add another button to toggle the display of the second hand on and off.

Hint: Review the role of the self.toggle method, and figure out how to do the same thing for the second hand display.

Exercise 12-3 Improving the display

This program redraws the clock hands and the date every 100 milliseconds, but it also redraws things that do not change. The date and position of the second hand change every second, but the minute hand and hour hand only change every minute. Think about how you can make it so the minute and hour hands are only redrawn if there has been a change since the last time it was drawn. Also, think about how to avoid the roughly second long delay that occurs when the screen is first displayed or when a button is pressed.

12.4 Coordinating actions using variables

In Program 12-2, when the button to turn on/off the date display is pressed, the value of the show_date variable is simply switched using the toggle() method that is set as the callback function. On the other hand, the display() method, which runs continuously on a timer, looks at the show_date variable and toggles the date display on and off.

You can use variables to create settings that coordinate the behavior of methods that work independently of each other. Variables such as show_date are called flags because they are used to raise and lower flags.

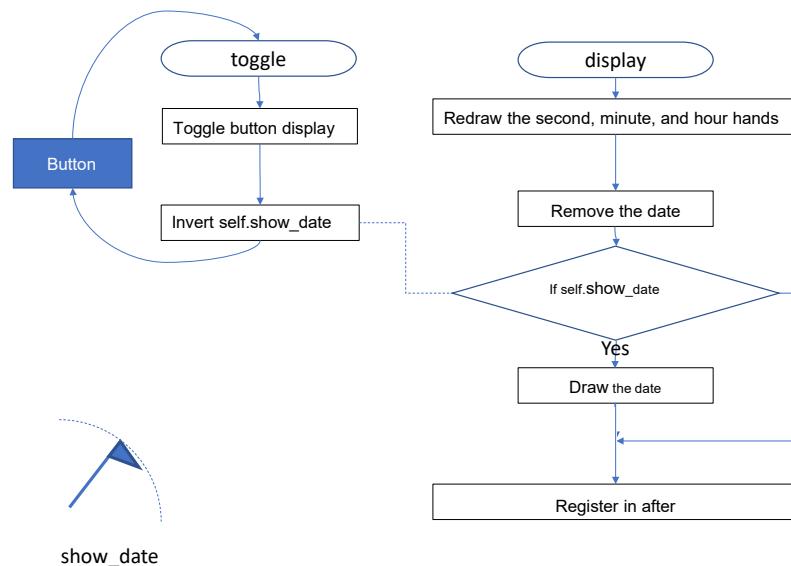


Figure 12-4 Coordinating actions using variables

13. Classes

13.1 Learning goals of this chapter

You have already used class objects in turtle graphics and tkinter. Here, you will learn about classes in more detail.

- You will learn about the concept of object-oriented programming.
- You will define and use classes.
- You will learn about variables that are used in classes.

13.2 Object-oriented programming

To handle multiple turtles in turtle graphics, we did the following.

- Generate as many turtles as needed.
- Call methods on individual turtles to tell them what to do and query their status.

Each turtle had its own state, which included its position, orientation, pen color, and whether or not the pen was down.

Objects are things like these turtles that have their own internal state and can be instructed to behave by calling methods from outside. Programming with objects is called object-oriented programming.

In the tkinter analog clock example, programming was done by extending the Frame class of tkinter. **A “class” is a description of a type that can be used to generate objects with unique states and methods.** Each object generated from a class is called an **“instance.”**

In short:

- An object (of a class type) is an element of a program with its own state (variables) and methods, **like a robot** that you can order around (as we did with the turtles).
- A class is a description of what variables and methods an object of that type has; it is a type used to create objects.
- An instance is an individual object generated with a class as its type.
- Object-oriented programming is a method of creating programs by defining classes and using generated instances of them. It is a concept that can be described as **writing programs to coordinate the behavior of robots.**

13.3 How to write and use classes in Python

As in the tkinter example, we will create a character user interface (CUI) type program that performs binary operations. we will use a class to organize the variables that hold the first and second terms, the result of the operation, the operator, and the method that actually performs the operation.

13.3.1 Source code

Program 13-1 CUI calculator program (p13-1.py)

Row	Source code	Notes
1	class Calculator(): 2 def __init__(self): 3 self.first_term=0 4 self.second_term=0 5 self.result=0 6 self.operation="+" 7 8 def do_operation(self): 9 if self.operation=="+": 10 self.result=self.first_term+self.second_term 11 elif self.operation=="-": 12 self.result=self.first_term-self.second_term 13 14 # Main program starts here 15 calculator=Calculator() 16 while True: 17 f=int(input("First term")) 18 calculator.first_term=f 19 o=input("Operation") 20 calculator.operation=o 21 s=int(input("Second term")) 22 calculator.second_term=s 23 calculator.do_operation() 24 r=calculator.result 25 print("Result",r)	Initialization method
10		Method to perform operations
15		Create an object

Example

```

First term 1
Operation +
Second term 2
Result 3
First term 10
Operation -
Second term 5
Result 5
First term Press Ctrl-C to interrupt
Traceback (most recent call last):
  File "M:/Documents/Python Scripts/class_demo.py", line 17, in <module>
    f = int(input("First term "))
KeyboardInterrupt
>>>
```

13.3.2 Overview of the program

- Class definition block (lines 1-12): **classes are defined** as follows.

```
class ClassName ():
```

Definition of methods, etc.

- The name of the class (Calculator in this example) can be determined by the same rules as for variables, but the convention is to capitalize the first letter and write the rest in lowercase. When using multiple words in a name, “camel case” is used, whereby the first letter of each word is capitalized (with no spaces in between words) and the rest of the letters are lowercase. (For example, FunctionCalculator)
- The definition of the method `__init__(self)` (lines 2-6): methods and variables beginning with `__` (two underscores) often have special roles in Python.
`__init__()` is a method that is executed whenever a class object is created.
 It is used to initialize variables in the class, and it is also called a "constructor" because it takes a role of making a object. Reference the column titled " Personification." Unlike functions, **class method definitions must always contain a parameter, which is usually named self by convention**. The value of this parameter is automatically given by the system when the method is called. There is no need to write the first argument when calling a class method.
- Instance variables and initialization (lines 3-6): The `__init__()` method initializes the variables used in the class.
 - Variables that begin with `self.` are called “instance variables.” They are object-specific variables that can always be used within the object whenever an object of that class is created.
 - On the other hand, variables without `self.` are treated as local variables like in functions, and are discarded when the method is finished processing.
- Definition of the method `do_operation()` (lines 8-12): This is a method that can be called explicitly, which performs the specified operation on the first and second terms and prints the result. Note the `self.` in the code; the parameter `self` is attached to the instance variables when they are processed.
- Main program (line 14 onward): This is a calculator program that receives text input from the terminal and executes it. It is written in an infinite loop, so use Ctrl-C to escape.
- Generating a class-type object** (line 15). Class-type objects are created by calling the class name like a function and assigning it to a variable.

```
Variable = ClassName ()
```

- Manipulation of instance variables and methods of class-type objects (lines 18-24). By appending a `.` followed by an instance variable name or method name to the class object variable, you can call these methods or variables. Note that the `do_operation()` method requires the parameter `self` in the definition, but does not require it when it is called.

Exercise 13-1 Extention of Calculator Class

Extend the Calculator class to handle multiplication and division. You may return just an integer quotient for division.

Exercise 13-2 Creation and Utilization of Multiple Objects

Create a program that generates and uses multiple objects of the Calculator class. Think about what you can do if you are able to utilize many robots that do addition. For example, how about a robot that does addition and another that monitors it, then checks the figures (does subtraction)?

Exercise 13-3 User Calculator Class in the Tkinter Program

Modify the calculator program created by tkinter so that it uses the Calculator class

13.4 Class variables and access restrictions

We mentioned earlier that Python programs have global variables that are valid for the entire program and local variables that are valid only while executing within a function. You also need to learn about class variables and instance variables when working with classes.

● Class Variables

- Creation: Declared in the class definition, outside of the method definition.
- Behavior: Acts as a variable shared by the class.
- Access: Can be referenced without creating a class object by writing `ClassName.variablename` in the code.

● Instance Variables

- Creation: Declared by adding the `self.` prefix in the method definition.
- Behavior: Each instance that is created is treated as an independent variable. The value is retained as long as the instance is in use.
- Access: In the definition of a method, refer to it by adding the `self.` prefix as you do when creating it.

To reference an instance variable in a program that used the created instance, the variable to which the instance is assigned (e.g., `a`) is referenced by writing the name, followed by a period (`.`), followed by the name of the instance variable.

Python does not have a very strong variable protection feature. Both class variables and instance variables can be referenced and rewritten externally. One way to restrict access from outside the class is to **use variables that begin with two underscores**. Such variables can be accessed by methods in the class, but cannot be manipulated directly from outside the class.

Program 13-2 Class variables and instance variables (p13-2.py)

Row	Source code	Notes
1	#_Class_practice	
2	class MyClass():	
3	# The following are class variables	
4	a = "My Class"	
5	__b = 0	__b is an access-protected variable
6		
7	# The following is the function called to create mydata, giving the initial value of the mydata as a parameter	
8		
9	def __init__(self, data):	This is an initialization method that takes parameter data
10	# __number is a serial number given to the instance	
11	self.__number = MyClass.__b	
12	self.mydata = data	
13	print("MyClass Object is created, number:", self.__number)	
14	# Increase the value of the class variable by 1	
15	MyClass.__b += 1	
16		
17	# Method that displays the serial number	
18	def show_number(self):	
19	print(self.__number)	
20		
21	#	
22	# Main program from here	
23	#	
24	if __name__ == "__main__":	Does not execute when imported as a module, according to the instructions in line 24
25	print("Class Variable a of MyClass:", MyClass.a)	
26		
27	instance1 = MyClass(1)	
28	instance2 = MyClass(10)	
29		
30	instance1.show_number()	
31	instance2.show_number()	
32		
33	print("mydata of instance1:", instance1.mydata)	
34	print("mydata of instance2:", instance2.mydata)	
35	instance1.mydata += 1	
36	instance2.mydata += 2	
37	print("mydata of instance1:", instance1.mydata)	
38	print("mydata of instance2:", instance2.mydata)	

If you run this program, you will get the following. You can see that the instances are numbered using class variables, that the instance variable mydata is independent for each instance, and that it can be accessed directly from the main program.

```

Class Variable a of MyClass: My Class
MyClass Object is created, number: 0
MyClass Object is created, number: 1
0
1
mydata of instance1: 1
mydata of instance2: 10
mydata of instance1: 2
mydata of instance2: 12

```

Also, the following operation will cause an error in the shell. You can see that instance variables that start with “`__`” are protected.

```

>>> print(instance1.__number)
Traceback (most recent call last):
File "<pyshell#46>", line 1, in <module>
    print(instance1.__number)
AttributeError: 'MyClass' object has no attribute '__number'

```

Note that the line:

```
if __name__ == "__main__":
```

in the source code indicates that this code will only be executed when the current file is run as the main program. It is possible to import this source code as a module, but in that case, anything below this line will not be executed.

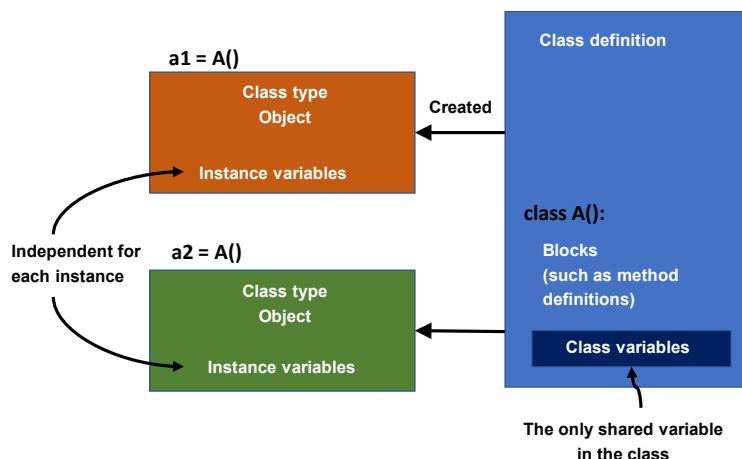


Figure 13-1 Class and Instance Variables

13.5 Inheritance

Inheritance is an important aspect of writing programs using classes. For example, in the example of tkinter implementation, the MyFrame class we defined inherited from tkinter's Frame class. MyFrame inherits the functionality of the Frame class and adds the definition of widgets on the Frame.

13.6 Designing classes starting from instances

Classes are a powerful tool for creating programs that do complex things. As we saw earlier, a class is a “type” that creates objects of a class type (instances). However, **it is difficult to think of things in terms of types.**

When actually designing a class, it is best to think in terms of specific instances, as shown below.

- Consider the data (candidates for instance variables) and operations (candidates for methods) that you want to handle together as a single object.
- Consider a class for each such object.
- Make the classes more widely available.
 - If multiple objects (classes) are the same, then the same class can be used for those objects.
 - If the only difference is values that are set, consider assigning the value to an instance variable and giving it as an argument when the object is created.
 - If shared methods and individual methods are mixed, consider inheritance.

14. File Input/Output

14.1 Learning goals of this chapter

1. Learn about text files as they are used in Python.
2. Learn how to use spreadsheet software dealing with CSV files to handle the results of Python calculations.
3. Learn how to read and write text files in Python.
4. Learn about filedialog in tkinter to assist in selecting files.

14.2 How to store data permanently

In conventional programs, data set to variables in the program is retained only while the program is running, and is erased when the program is terminated.

In addition, the input and output of a program, whether GUI or CUI, is input by a human, and the results are read by a human.

In order to use data permanently in a program, it is necessary to write and read data in a form that can be saved outside the program. Candidates for this are as follows:

- A file on the computer
- A database on a computer
- A service on a network

In this section, you will learn how to handle files on a computer, which is the basis of all of these methods.

14.3 Regarding files

14.3.1 File Path

Files on computers are managed by operating systems such as Windows, macOS, and linux. These operating systems have a hierarchical folder (directory)¹ structure, in which folders can be placed within folders, and the location of a file is identified by its position in the folder structure. The string describing the location of a file is called the “file path,” and is a combination of the “hierarchical folder structure notation” and the file name.

To give an example, in Windows

¹Windows uses folders as a mechanism for organizing files, while its predecessors, MS-DOS and unix, used the term “directory.” Strictly speaking, they are slightly different, but here we will treat folders and directories as the same thing.

`M:\documents\python scripts\p3-1.py`

is the file path. Depending on a used font, it may be represented as

`M:\documents\python scripts\p3-1.py`

Here

M: the drive name (corresponding to the disk device or file server)

\document\python_scripts: folder path

p3-1.py: file name

.py: everything after the “.” in a file name is called the “**extension**,” which indicates the file type.

A full path starts at the drive name and includes all of the folders. A full path is the only way to identify a specific file on a computer.

In addition to this, there is a “current working folder [directory]” that is referred to as the current working directory, (cwd), as well as a “relative path” which is a path that describes only the differences from the specified folder. For example, if your working folder is

`M:\documents\python scripts`

then the relative path notation

`p3-1.py`

would refer to

`M:\documents\python scripts\p3-1.py`

14.3.2 Use of Raw String

When you write file path directly in a source code, you should know Python treats '\ for special meaning, e.g, '\n' means newline. Since a filepath often uses '\ for separator of folders, you have to write two '\s for each '\

```
filepath = "M:\documents\python scripts\p3-1.py"
```

or use prefix 'r' to treat the string as it is:

```
filepath = r"M:\documents\python scripts\p3-1.py"
```

Reference the column titled " Escaping."

14.3.3 Text Files

A text file is a file written in text code (and symbols such as line breaks) in a format that can be read and written by humans using an editor. For example, Python source code and email messages are text files.

On the other hand, a file consisting of data in a computer's internal format is called a “binary file.” The word “binary” means “base-2.” Binary files are written in the computer's internal format with no

change; they have the advantage of not losing numerical value accuracy, and taking up a small amount of data. However, without a description of the file's contents, it's not possible to tell what is written in a binary file.

In this chapter, you will learn how to read and write text files in Python.

14.3.4 CSV format

Python programs can be used in conjunction with other tools without much effort. The **CSV (comma separated value) format** is an easy way to handle data for this purpose. This is a type of text file in which each line consists of:

Data entry 1, Data entry 2, Data entry 3

and so on, with commas separating the data. If you add the extension .csv to the file name of a file in this format, it can be read by spreadsheet software such as Microsoft Excel, making it easy to create graphs.

Data in the CSV format is **relatively easy to output**. On the other hand, reading data in the CSV format data can be tricky due to the handling of comma and line break characters; depending on the content of your data, you may want to consider using a library¹ or other method.

14.3.5 Character Encoding Issues

Due to the historical nature of the Japanese language, there are several different character encodings that are used on different operating systems. For example, the character codes used for Japanese file names are as follows

- Mac, Linux: Unicode
- Windows: Shift-JIS

In text files, in addition to the above differences in character encoding, there are also differences in the code used to represent a line break.

- Python 3 uses UTF-8 internally, which is one of the Unicode representations. Python programs (scripts) created in IDLE are coded and stored in UTF-8 as well. If you are running Python on a single OS, you don't need to worry too much about the differences between OSes, as Python will adjust accordingly. You need to be careful when running the program on different operating systems, however.

14.3.6 Error Handling

Error handling is extremely important for file input/output. This is because the contents of files, the file system, and the data to be read cannot be controlled by the program. When you try to open a file, you must be aware that various things may happen. For example, the file or folder may not exist, you may not have write permission, or you may run out of disk space in the middle of writing a file.

¹In Python, the csv module is a library for handling CSV. In a later chapter we will see an example of loading a CSV file with pandas.

14.4 Let's try to run the code below first.

14.4.1 Source code

Program 14-1 Example of File Input/Output (p14-1.py)

Row	Source code	Notes
1	# Import the OS module to find out the current working directory (the folder where you are working)	
2	import os	
3		
4	# Get the current working directory and print it on the screen	
5	print(os.getcwd())	
6	# Create a file named 'Japanese_file.txt' and write fill it in	
7	f = open('Japanese-File.txt', 'w')	
8	f.write('日本語\n日本語\n日本語\n')	
9	f.close()	Write text in Kanji. On Windows, "\\" may be shown as "\\\"
10	# Open Japanese_file.txt for reading to display its contents	
11	f = open('Japanese-File.txt', 'r')	
12	s = f.read()	
13	f.close()	
14	print(s)	

14.4.2 Program Notes

- Figure out the current working folder (current working directory) (line 8)
- Open the file named “Japanese file.txt” for writing (w), and assign it to the variable “f” for future use. It is written as a relative path, so it will be created in the working folder with this name. (line 10)
- Write the string to a file (line 11). “\n” means “new line.”
- Close the writing file (line 12)
- Open a file with the same name for reading (r). (line 15)
- Assign the entire contents of the file to the variable s. (Line 16)
- Close the file (line 17)
- Output the data (text) (line 18)

14.5 Reading and writing files in Python

14.5.1 Using the open Function

Files can be manipulated as per the following procedure.

1. Open the file with the open function and get the file object in the return value.

```
file = open(file_name, mode)
```

The mode can be “r” for reading, “w” for writing, etc. In the above example, the return value is assigned to the variable file.

In Python, unless otherwise specified, text files are written in the standard character set of the operating system, and the encoding argument can be used to explicitly specify the character set.

```
file = open(file_name, mode, encoding= "utf-8")
```

If it fails to open the file, it raises an IOError exception.

2. Reading and writing to a file object

- A. Reading from a file object using the read() method

```
s = file.read()
```

In the above example, the entire text file is read as a string and assigned to the variable s.

- B. Writing to a file object using the write() method

```
file.write(s)
```

The above example writes data in s to the file as a string.

The data can be added in the same way until the file is closed.

3. Close the file

```
file.close()
```

Note: open is a built-in function, and read, write, and close are methods of the file object.

In the above example, the entire contents of the file are read at once; to read a single line, use the readline() method. It is also possible to process the contents of a file line by line using a for statement as follows ¹.

```
file = open("filename", "r")
for line in file:
    A block that works on each line one line at a time
```

14.5.2 Using the 'with' statement - Automating close()

A file opened with the open() function must be closed with the close() method, but in the following cases, the close() function may not be performed.

- You simply forgot to call the close() method.

¹ Python's 'for' statement can be applied to a variety of objects, such as range() functions, strings (one character at a time), lists (element by element), etc. This is because they are iterable, which means that they can be iterated over. File objects are also iterable, where iterations occur line by line.

- The close() method is not executed due to an error in the code where it is written.

To avoid this, Python provides 'with' statement, which automatically closes the file opened by the with statement after the block ends.

with open(File name and other arguments of the open function) as variables for the file object :

A block that manipulates the file

14.6 Example 1 Wave approximation

14.6.1 Key points in the example below

- Since it is cumbersome to input the exact file path from a terminal, tkinter (only the filedialog module) is used.
- The calculation results are output in CSV format and linked to spreadsheet software.
- As an example, we will use an example that expresses a periodic function as a sum of trigonometric functions.

14.6.2 Approximation of Periodic Function by Sum of Trigonometric Functions

It is known that a periodic function (a function whose value repeats with a certain period) can be approximated by the sum of sine (sin) and cosine (cos) functions that are integer multiples of the frequency. A sawtooth wave can be approximated as follows (see also the column titled “Trigonometric Functions”).

$$f(x) = \frac{\sin(x)}{1} + \frac{\sin(2x)}{2} + \frac{\sin(3x)}{3} + \frac{\sin(4x)}{4} \dots$$

The figure below plots the sum of the first through fifth terms.

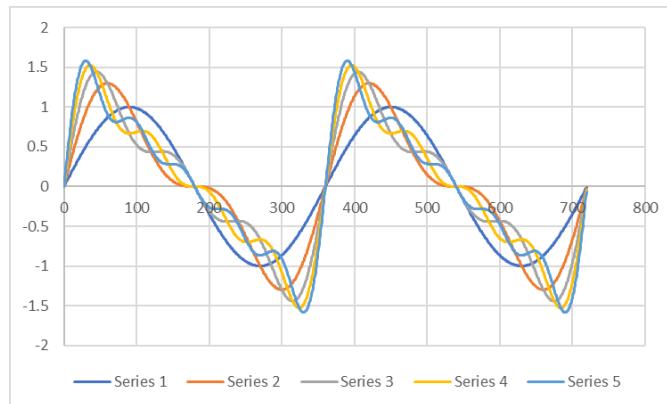


Figure 14-1 Approximation of a sawtooth wave by summing trigonometric functions

For simplicity, the signs of the terms shown above are all the same, but for the sawtooth wave (that has a positive slope at the origin), the signs change alternately as shown below.

$$f(x) = \frac{\sin(x)}{1} - \frac{\sin(2x)}{2} + \frac{\sin(3x)}{3} - \frac{\sin(4x)}{4} \dots$$

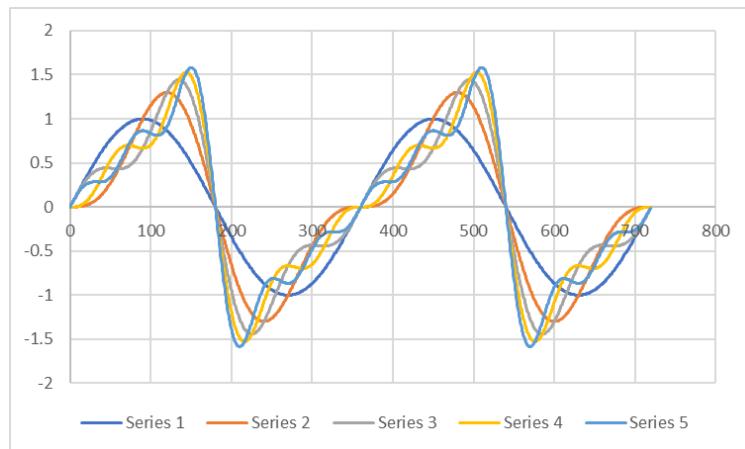


Figure 14-2 Approximation of a sawtooth wave by summing trigonometric functions (with positive slope at the origin)

A sawtooth wave with an amplitude of 1 (maximum and minimum values are ± 1) has a coefficient ($2/\pi$) applied to the whole wave.

14.6.3 Source code

Program 14-2 Approximation of a sawtooth wave by summing trigonometric functions (p14-2.py)

Row	Source code	Notes
1	import tkinter as tk	
2	import tkinter.filedialog	
3	import math	
4	#	
5	# Example of using only tkinter's filedialog	Import filedialog as well
6	#	
7	# Hide the root window by reading the withdraw() method	
8	root = tk.Tk()	
9	root.withdraw()	
10	#	
11	# Read the filedialog for writing and get the file name.	
12	#	
13	filename = tkinter.filedialog.asksaveasfilename()	
14	#	
15	# Close tkinter	Get the file name from the dialog and go back.
16	#	tkinter is no longer used, so it is closed.
17	root.destroy()	
18	#	
19	# If you don't get a file name, close it	
20	#	
21	if filename:	
22	pass	pass is a command that does not do anything.
23	else:	
24	print("No file specified")	
25	exit()	
26	#	
27	# Approximate a saw wave by superimposing sine waves upon one another	
28	#	
29	# w = sin(t) + sin(2t)/2 + sin(3t)/3 + sin(4t)/4 ...	
30	#	
31	# 2 periods worth, 1000 steps overall, harmonics up to the 5th	
32	#	
33	cycles = 2	
34	steps = 1000	
35	harmonics = 5	
36	# Error handling when a file cannot be opened	
37	try:	
38	# Open the file	
39	with open(filename, 'w') as file:	
40	for i in range(steps):	

<pre> 41 angle_in_degree = 360*cycles*steps 42 angle = math.radians(angle_in_degree) 43 s = str(angle_in_degree) 44 w = 0 45 for j in range(1,harmonics+1): 46 w+=math.sin(angle*j)/j 47 s=s+","+str(w) 48 #print(s) 49 file.write(s+"\n") 50 print("Writing to file "+filename+" is finished") 51 except IOError: 52 print("Unable to open file") </pre>	<p>Express the angle as a string</p> <p>Concatenate sum w to s, separated by a comma (,)</p> <p>Add a line break "\n" and write it</p> <p>Append s to the file.</p>
---	---

14.6.4 Program Notes

1) Use of tkinter's filedialog (lines 1-25)

- When you open or save a file in a Windows application, you can find or specify the file in a separate window. tkinter provides a filedialog mechanism for this purpose. In this program, the main window of tkinter is created in line 8. Because we use only the filedialog function, the main window of tkinter is hidden in line 9. Also note that the mainloop() method is not called.
- There are several formats for filedialog depending on the intended use, but in this case, the asksaveasfilename() method for "save as" is called in line 13, and the filename is set to the file name (path name) obtained by the return value.
- Since tkinter is not needed when coming back from filedialog, root.destroy() terminates tkinter.
- If the user does something such as cancel the program, the filename will be empty, so the program will be terminated when the if statement is false.
- For more information on using filedialog for reading, refer to the following example.

2) Calculation and file output (lines 23 to 53)

- This part calculates the superposition of trigonometric functions and outputs it in CSV format.
- For file handling, it is necessary to deal with an error such as when the program is not able to open the file. In line 37, a block that manipulates the file with a try statement handles this. The corresponding error handling is in lines 52 and 53.
- In line 40, a with statement is used to open a file with filename obtained from filedialog, and the opened file is handled by the variable file.
- One line of computation and output is as follows:
angle, first term, sum up to second term, sum up to third term, sum up to fourth term, sum up to fifth term.

The summation is computed in the variable w, and the contents of a line are added to the variable s as a string. To make the CSV format, the value of w is converted to a string and concatenated to s separated by a comma (,) as follows:

```
s = s+", "+ str(w)
```

The comma is followed by a ¹ space to make the resulting file easier to read.

- After the computation up to the fifth term in the for statement is completed, lines 49 and 50 are output to a file.

```
#     print(s)
file.write(s+"\n")
```

Line 49 is commented, but if you want to see the result in the Python shell, remove the #. In line 50, file.write() writes to the file, but “\n” is added to the single-line string s to add a “line break.” Mac users should enter a backslash “\” instead of “¥.”

Exercise 14-1 Square wave approximation

A square wave (a periodic function that alternates between values of ± 1) can be approximated by a trigonometric function as follows ²

$$f(x) = \frac{\sin(x)}{1} + \frac{\sin(3x)}{3} + \frac{\sin(5x)}{5} + \frac{\sin(7x)}{7} \dots$$

Calculate the trigonometric approximation for the square wave in the same way as in the example, output the result to a CSV file, and create a graph using spreadsheet software.

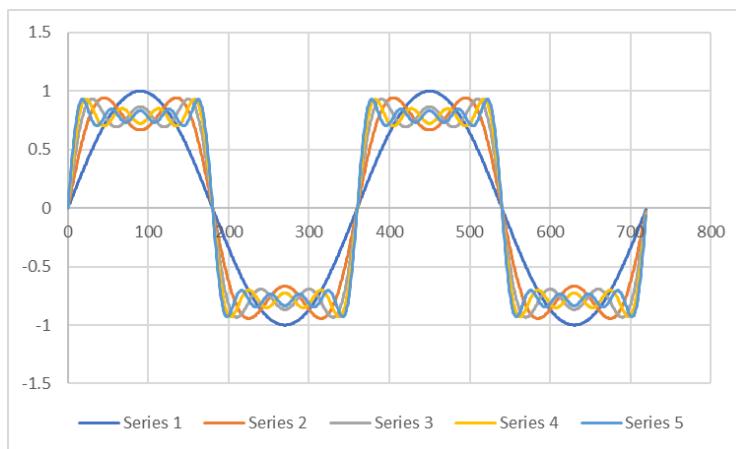


Figure 14-3 Approximation of a square wave by summing trigonometric functions

Exercise 14-2 Implementation of the list from Example 1

In the program in Example 1, the results of the calculations were concatenated as strings and written to a file one line at a time. Reimplement this program as follows, separating the calculation and

¹Turing part of a program that could otherwise be executed into a comment is called “commenting out,” and is often used to check the operation of a program.

² For a square wave of amplitude 1, a factor of $4/\pi$ is applied to the whole wave.

output.

- Write the result of the calculation to a list using a list.
- After the calculation is completed, write a CSV file in the same format as in Example 1 that refers to the list.

There are two ways of constructing a list, as follows. Either implementation method is acceptable.

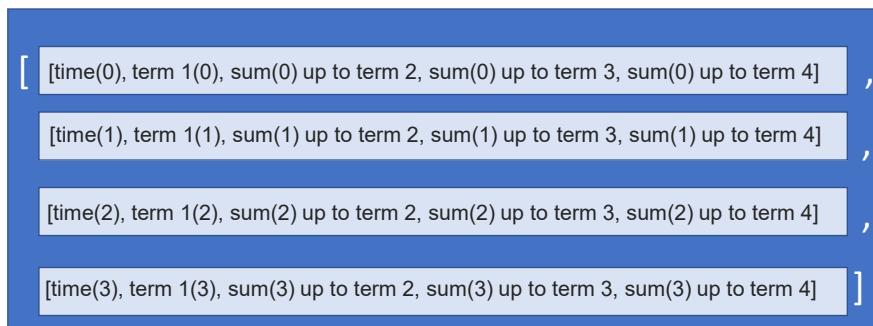


Figure 14-4 Using a “list of data at different time points”

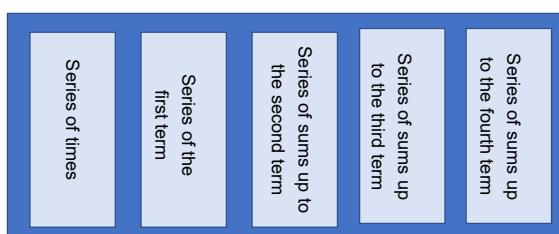


Figure 14-5 Using a “list of each series”

14.7 Example 2 Text Editor

You can create a simple text editor using tkinter. tkinter has all the features you have learned so far, as well as the messagebox dialog for displaying messages, the filedialog method for reading files, the tkinter Menu widget, Text widget, etc. For the geometry manager, we will use 'pack' instead of 'grid' for simplicity.

The Kanji encoding for the files is not specified, so Python assumes the standard encoding for each OS. On Windows, it is assumed that Shift-JIS code (cp932) is used.

Program 14-3 A simple text editor using tkinter (p14-3.py)

Row	Source code
1	import tkinter as tk
2	import tkinter.messagebox
3	import tkinter.filedialog
4	#messagebox_and_filedialog_need_to_be_imported_explicitly

```

5  #
6  # Create a class called MyFrame that inherits from tk.Frame
7  # Set up widgets and callback functions (methods) in init.
8  # This is the standard way to use tkinter.
9  #
10 class MyFrame(tk.Frame):
11     #__init__ is the initialization method for creating a class object
12     def __init__(self, master=None):
13         super().__init__(master)
14         self.master.title('Simple Editor')
15
16     # Create a menu: menubar->filemenu->Open, Save as, Exit
17     menubar = tk.Menu(self)
18     filemenu = tk.Menu(menubar, tearoff=0)
19     filemenu.add_command(label="Open", command=self.openfile)
20     filemenu.add_command(label="Save as...", command=self.saveas)
21     filemenu.add_command(label="Exit", command=self.master.destroy)
22     menubar.add_cascade(label="File", menu=filemenu)
23     self.master.config(menu=menubar)
24
25     # Create a Text widget for editing as a class variable using editbox
26     self.editbox = tk.Text(self)
27     self.editbox.pack()
28
29     # Method to open a file, requires the parameter "self"
30     # which is different than the parameter that a function would take
31     def openfile(self):
32         # Get the filename in filedialog
33         filename = tkinter.filedialog.askopenfilename()
34         # Process the filename if it's not empty
35         if filename:
36             tkinter.messagebox.showinfo("Filename", "Open: " + filename)
37             # Open a file with a variable named file in it using a with statement
38             with open(filename, 'r') as file:
39                 text = file.read()
40             # Set the file contents in the editbox Text widget
41             self.editbox.delete('1.0', tk.END)
42             self.editbox.insert('1.0', text)
43         else:
44             tkinter.messagebox.showinfo("Filename", "Canceled")
45
46     # Method to save to a file
47     def saveas(self):
48         # open a file with a variable named file using a with statement
49         filename = tkinter.filedialog.asksaveasfilename()
50         if filename:
51             with open(filename, 'w') as file:
52                 file.write(self.editbox.get('1.0', tk.END))

```

```
52     tkinter.messagebox.showinfo("Filename","Saved_AS:"+filename)
53 else:
54     tkinter.messagebox.showinfo("Filename","Canceled")
55
56 #Main_program_from_here
57 root=tk.Tk()
58 f=MyFrame(root)
59 f.pack()
60 f.mainloop()
```

15. Learning Program Development with Tic-Tac-Toe

15.1 Learning goals of this chapter

In this chapter, you will do the following to learn how to develop a program, using tic-tac-toe as an example.

1. Analyze how to play tic-tac-toe, and identify what needs to be expressed in the program.
2. Prepare a game record for testing the program.
3. Create the data and functions that make up the program, starting with the smallest.
4. Assemble the whole program to complete the tic-tac-toe program.

15.2 Developing a program

As seen in the previous programs, it is difficult for beginners to create a program when given a specific task. This is because being able to use the various elements of a programming language and developing a coherent program from scratch are two different skills. For example, **just because you can use a hammer and a saw doesn't mean you can build a house**, because to build a house, you need to know what it consists of and in what order it needs to be designed and constructed. The same applies to programs.

15.3 Design procedure - what to do before using your computer

You often see beginners open their computer to create a program only to end up getting stuck. Why does that happen?

The procedure for designing and creating a program is as follows. You don't necessarily need the computer at first, but because you are facing the computer screen, you may get stuck.

- What to do before using a computer
 - Describe what you want to achieve in words
 - Identify what you need the program to do
 - ❖ What to express as variables
 - ❖ What values each variable will have
 - ❖ What should be expressed as a protocol (function)
 - ❖ What should be expressed as an interaction with people

- Decide the order in which to create the program
- Decide how to test it
- This is where the work on the computer begins
 - Create the program (functions) starting with the parts that do not depend on others
 - Test the functions you create (unit testing)
 - Test the whole program (integration testing)

15.4 Designing a simple tic-tac-toe program

15.4.1 Tic-Tac-Toe

Describe in words the rules of tic-tac-toe and how the game proceeds.

○	×	
	○	
○		×

15.4.2 Sentence analysis

Analyze the sentences you made that describe the rules of tic-tac-toe and the progression of the game in terms of parts of speech (nouns, copulas, verbs).¹ You will end up with points similar to those below.

- Items (nouns) that take a specific state: these are candidates for variables
 - 3×3 board, turn
- The state of items (copulas): possible values for the variables
 - The state of each square (empty, O (player one), X (player two))
 - Whose turn it is
- Actions that check states (candidates for functions)
 - Whose turn it is
 - State of the squares
 - Player one wins, player two wins, draw
- Changing the state of a square (this is a candidate for a function)
 - Placing O or X in a square
 - Alternating turns

¹This existence of such tasks is why literacy in the humanities is important for programmers.

15.4.3 Creating a Game Record (to Prepare for Testing)

Before you build your program, you should make some test board game records. It is difficult to cover all cases, but here are some cases to consider.

- Must include cases where player one wins, player two wins, and there is a draw
- Include all the different winning patterns (vertical (3 ways), horizontal (3 ways), diagonal (2 ways))

Preparing test cases first is called “**test first programming**;” it is more effective than “coding first,” which is where you start building the program first, in the following reasons

- You're less likely to create test cases if you start later
- You can test these cases at any time during the creation of the program
- Test cases can help you to be aware of the need to test during coding

Turn	row	column	row	column	row	column	
1 O	0	0	0	0	0	1	
Result	Draw			Player one wins		Player two wins	
	0	1	2	0	1	2	
	0 1 O	6 X	5 O	0 1 O	6 X	5 O	
	1 3 O	2 X	9 O	1 2 X	3 O		
	2 4 X	7 O	8 X	2 7 O	4 X		

Figure 15-1 Example tic-tac-toe game records

15.4.4 Variable design

1) The board

- The 3×3 board is represented by a nested list in which the elements are integers.
`board = [[0, 0, 0], [0, 0, 0], [0, 0, 0]]`
- The initial state is all 0s (empty)
- The meaning of the values is as follows: 0 is an empty space, 1 is for player one (O), and 2 for player two (X).
- For this purpose, we define constants (there is no way to forbid changing the values in Python). We use uppercase letters to make it clear that they are constants. we also use the following

constants to consider the turn and result.

```
OPEN = 0
FIRST = 1
SECOND = 2
DRAW = 3
```

2) Turn

- An integer variable will indicate which player's turn it is. The initial value is FIRST (the first move)

```
turn = FIRST
```

- The values use the previous constants (FIRST, SECOND), where FIRST indicates that it is player one's turn, and SECOND indicates that it is player two's turn

3) Game record

- The turn order is always “player one, then player two, then player one...” The move made by each player is represented in the list of rows and columns.
- We then append the result (undecided, player one wins, player two wins, draw) to this list ¹.
- Game Record = [[first move (row, column)], [second move (row, column)], ..., [last move (row, column)], [result]]
- The row and column can be represented by an integer value of either 0, 1, or 2. The result can be represented by an integer value of 0, 1, 2, or 3.

15.4.5 Functions concerning the board and turns

Create functions to “operate” on the state, “check” the state, “display” it on the screen, initialize it (a type of operation), etc.

The board and the turn are shared as global variables, so a global declaration is required to change the values of variables outside the function from within a function. Functions such as those below may be needed.

1) Turns

- Operation: Initialize the turn
- Operation: Change whose turn it is
- Display: Display the turn (generate a string for it)

¹ Because the game record is represented by a single list, different list elements actually represent two different things (where the players moved, and the result). This is admittedly not a very straightforward implementation.

2) The Board

- Operation: Initialize the board
- Operation: Mark the specified square on the board with the marker of the player whose turn it is
- Check: Determine the state of individual squares on the board
- Check: Determine which player wins the game, based on the board
- Check: Determine if all squares on the board are occupied
- Display: Output the entire board (generate it as a string)

3) Game Records

- Operation: Replay a game using the game record.

4) Algorithm for determining the winner

If you try to explicitly write out a method of determining the winner of a game of tic-tac-toe as you play it in your daily life, it would be as follows.

- Determine whether the turn (denoted by t) results in victory in a given row or column.
 - If all the spots in the three positions in row/column of interest are t, then t wins.
 - Otherwise, t does not win
- Determine if the game is won in a certain direction (horizontal, vertical, diagonal, reverse diagonal)
 - If horizontal or vertical
 - ✧ if the game is won in row 0 (column 0), t wins
 - ✧ If not, then if the game is won in row 1 (column 1), t wins
 - ✧ If not, then if the game is won in row 2 (column 2), t wins
 - ✧ Otherwise, t does not win
 - If the game is won in the diagonal or reverse diagonal line, then t wins
- Determining victory based on the above
 1. If the game is won horizontally, then t wins.
 2. If not, then if the game is won vertically, t wins.
 3. If not, then if the game is won diagonally, t wins.
 4. If not, then if the game is won reverse diagonally, t wins.
 5. Otherwise, t does not win

Also, while it is not possible on a board where victory is checked for every turn, on a randomly generated board, it is possible to have a case where both player one and player two win.

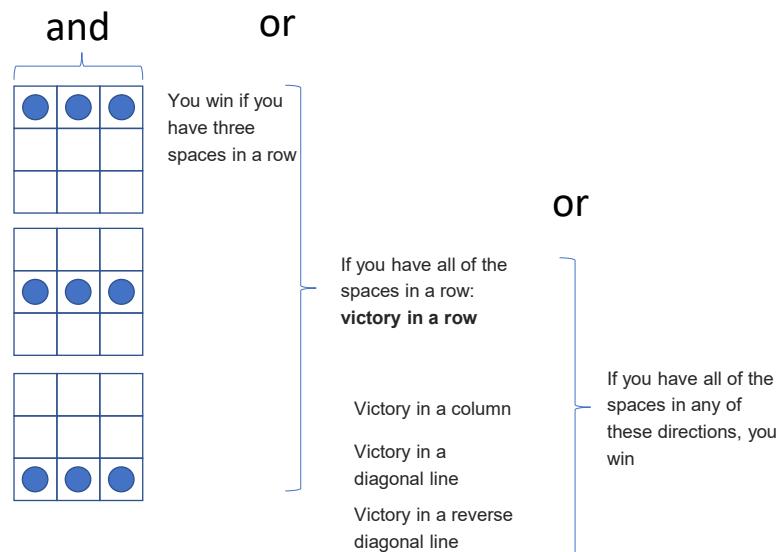


Figure 15-2 Determining victory for the turn in question

- Determining the winner

Using the above procedure (function), you can determine the winner of a game of tic-tac-toe as follows.

1. Check whether player one has won or not; if player one has won, then it is player one's victory.
2. If not, then check whether player two has won or not; if player two has won, then it is player two's victory.
3. If not, then if there is still an empty space on the board, then the game is unfinished.
4. If not (if there are no empty spaces on the board), the game is a draw.

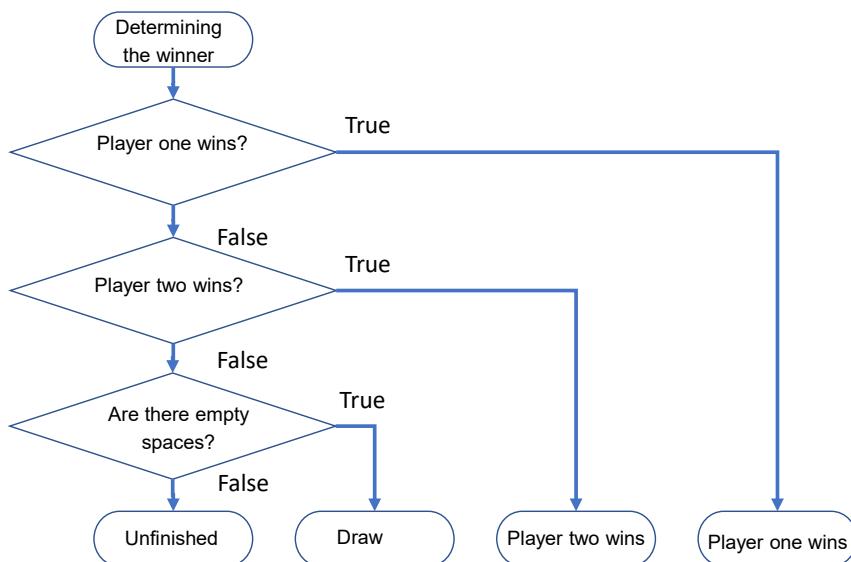


Figure 15-3 Determining the winner

15.4.6 How to write complex conditional decisions

As explained in Section 4, the determination of the winner of a tic-tac-toe game is actually quite complicated. For example, suppose you have three conditions: `is_A`, `is_B`, and `is_C` (think of these as variables or functions that take a value of True or False). The part of the function that decides if all of them are True is written as:

```
return is_A and is_B and is_C:
```

You could also nest the if statements as follows:

```
if is_A:  
    if is_B:  
        if is_C:  
            return True  
    return False
```

Also, you could write it as:

```
if not is_A:  
    return False  
if not is_B:  
    return False  
if not is_C:  
    return False  
return True
```

If you use that last way of writing it, then you could also write it as:

```
conditions = [is_A, is_B, is_C]  
for c in conditions:  
    if not c:  
        return False  
return True
```

In the last method, even if the number of conditions to be checked increases, the decision part can be written succinctly by using a for statement.

Exercise 15-1 Programming Branching with Complicated Condition

Based on the examples above, write a function that returns True if any of `is_A`, `is_B`, or `is_C` is True.

15.4.7 Progression of the game

Let's consider the flow of the main program. Input and output are done in the Python shell in the form of characters. You'll see how easy it is to implement using the functions you defined earlier.

- Initialize the game
- Display the board
- Repeat the following until the game is won, lost, or drawn:
 - Prompt the user for the input of the active player until a valid input is obtained.
 - ✧ Get input from the active player
 - Update the board
 - Display the board
 - Determine if the game is won, lost, or drawn
 - ✧ Show the result and escape the main loop if the game is over
 - Change the player's turn

15.5 Implementation of the program

1) Source code structure

Once the design is complete, you can start fleshing out the program. Check to see that your Python source code looks something like the following.

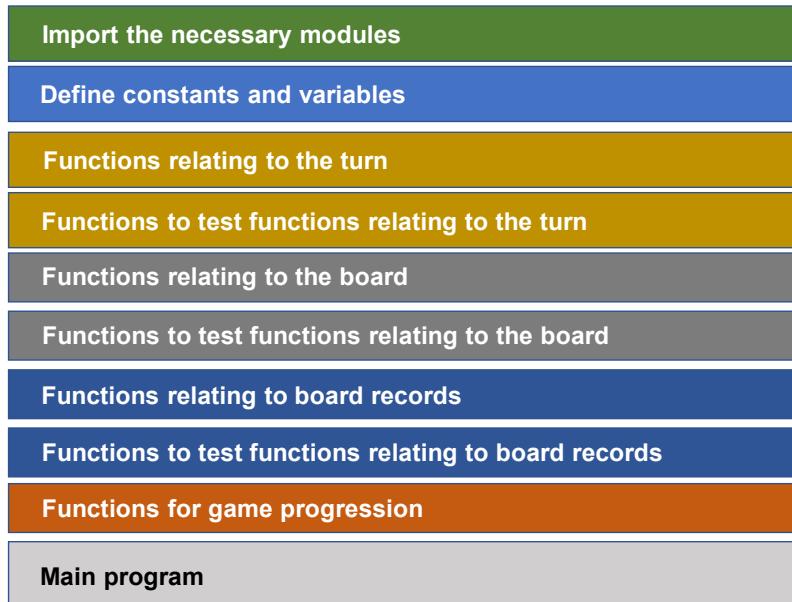


Figure 15-4 Overall source code structure

2) Example code (`tic_tac_toe.py`)

An example implementation of the program is shown below. Some notes concerning the way things were implemented and the notation are explained below.

- The program is implemented in the order shown in Figure 15-4.

- The program has nearly 500 lines in total, but the code with the yellow background is for testing functions.
- Functions come with a docstring. Multi-line docstrings start and end with "" (three single quotes).
- There are no modules that need to be imported.
- The display functions do not “print to the screen,” but generate a string that can be passed to the print() function.
- The main program simply prints “tic-tac-toe.” All the functions are loaded, so you can call them in Python shell for testing or for actual play.

Program 15-1 Tic-tac-toe program example (Part 1: Global variables)

Row	Source code
1	#
2	#_Tic-tac-toe
3	#
4	#_There_are_no_modules_that_need_to_be_imported.
5	#
6	#_Define_constants
7	#
8	#
9	#_Create_a_game_record_in_play()_(needs_to_be_completed).
10	#
11	'This_is_a_tic-tac-toe_program'
12	OPEN_=0
13	FIRST_=1
14	SECOND_=2
15	DRAW_=3
16	#
17	#_Constant_variable
18	#
19	turn_=FIRST
20	board_==[[0,0,0],[0,0,0],[0,0,0]]
21	#
22	#_Test_board_records
23	#
24	log1=[[0,0],[1,1],[1,0],[2,0],[0,2],[0,1],[2,1],[2,2],[1,2],[DRAW]]
25	log2=[[0,0],[1,0],[1,1],[2,2],[0,1],[2,0],[FIRST]]
26	log3=[[0,1],[0,0],[2,1],[1,1],[2,2],[2,0],[1,0],[0,2],[SECOND]]

Program 15-2 Tic-tac-toe program example (Part 2: Turn-related functions)

```

27  #
28  #_Functions_related_to_turns
29  #
30  #_Convert_the_move_number_to_a_string
31  #
32  def show_turn():
33      '''Return_a_string_showing_current_turn'''
34      if turn==FIRST:
35          return('First')
36      elif turn==SECOND:
37          return('Second')
38      else:
39          return('Value_of_turn_is_not_aequate')
40  #
41  #_Initialize_the_turn
42  #
43  def init_turn():
44      '''Initialize_turn'''
45      global turn
46      turn=FIRST
47  #
48  #_Change_the_turn
49  #
50  def change_turn():
51      '''Change_turn'''
52      global turn
53      if turn==FIRST:
54          turn=SECOND
55      elif turn==SECOND:
56          turn=FIRST
57  #
58  #_Test_turn-related_functions
59  #
60  def test_turn():
61      '''Test_program_of_turn'''
62      init_turn()
63      print(show_turn(),"is_the_current_turn")
64      change_turn()
65      print(show_turn(),"is_the_current_turn")
66      change_turn()
67      print(show_turn(),"is_the_current_turn")

```

Program 15-3 Tic-tac-toe program, example (Part 3: Board-related functions part 1)

```

68  #
69  #_Board-related_functions
70  #
71  #_A_string_that_displays_the_board
72  #
73  def show_board():
74      '''Return a string showing the current board'''
75      s=':012\n-----\n'
76      for i in range(3):
77          s=s+str(i)+':'
78          for j in range(3):
79              cell=''
80              if board[i][j]==OPEN:
81                  cell=' '
82              elif board[i][j]==FIRST:
83                  cell='0'
84              elif board[i][j]==SECOND:
85                  cell='X'
86              else:
87                  cell='?'
88              s=s+cell+' '
89          s=s+'\n'
90      return s
91  #
92  #_Initialize the board
93  #
94  def init_board():
95      '''Set all the places on board OPEN'''
96      for i in range(3):
97          for j in range(3):
98              board[i][j]=OPEN
99      #
100     #_Return the value of position i, j on the board
101    #
102    def examine_board(i,j):
103        '''Return state of the i-th row, j-th column place on the board'''
104        return board[i][j]
105    #
106    #_Register the turn t to i, j on the board, and return its status as a string
107    #
108    def set_board(i,j,t):
109        """
110        Set turn t on the i, j place of the board, and return the status
111        returned value will be
112        'ok' if successfully places
113        'Not empty' the place is not empty

```

```
114     ''illegal_turn' if turn value is not adequate
115     ''illegal_slot' if place is not adequate
116     ''
117     if (i>0) and (i<3) and (j>0) and (j<3):
118         if (t>0) and (t<3):
119             if examine_board(i,j)==0:
120                 board[i][j]=t
121                 return 'OK'
122             else:
123                 return 'Not empty'
124             else:
125                 return 'illegal_turn'
126             else:
127                 return 'illegal_slot'
128
129 # Testing function for the board
130 #
131 def test_board1():
132     'The first test program on the board'
133     init_board()
134     print(show_board())
135     print(set_board(0,0,1))
136     print(show_board())
137     print(set_board(1,1,2))
138     print(show_board())
139     print(set_board(1,1,1))
140     print(show_board())
```

Program 15-4 Tic-tac-toe program, example (Part 4: Board-related functions part 2)

```

141 #
142 # Determine if a turn t wins in the horizontal direction
143 #
144 def check_board_horizontal(t):
145     'Check whether turn t is win in horizontal direction'
146     for i in range(3):
147         if (board[i][0]==t) and (board[i][1]==t) and (board[i][2]==t):
148             return True
149     return False
150 #
151 # Determine if a turn t wins in the vertical direction
152 #
153 def check_board_vertical(t):
154     'Check whether turn t is win in vertical direction'
155     for j in range(3):
156         if (board[0][j]==t) and (board[1][j]==t) and (board[2][j]==t):
157             return True
158     return False
159 #
160 # Determine if a turn t wins in the diagonal direction
161 #
162 def check_board_diagonal(t):
163     'Check whether turn t is win in diagonal direction'
164     if (board[0][0]==t) and (board[1][1]==t) and (board[2][2]==t):
165         return True
166     return False
167 #
168 # Determine if a turn t wins in the reverse diagonal direction
169 #
170 def check_board_inverse_diagonal(t):
171     'Check whether turn t is win in inverse diagonal direction'
172     if (board[0][2]==t) and (board[1][1]==t) and (board[2][0]==t):
173         return True
174     return False
175 #
176 # Simple determination of victory for a turn t
177 #
178 def is_win_simple(t):
179     'Check win of turn. Do not check win of the other turn'
180     if check_board_horizontal(t):
181         return True
182     if check_board_vertical(t):
183         return True
184     if check_board_diagonal(t):
185         return True
186     if check_board_inverse_diagonal(t):

```

```
187     return True
188     return False
189 #
190 # Determine the winner by confirming the opponent has not won.
191 #
192 def is_win_actual(t):
193     'Check win of turn t. It also check whether the other turn do not win'
194     if not is_win_simple(t):
195         return False
196     if t==FIRST:
197         if is_win_simple(SECOND):
198             return False
199     else:
200         if is_win_simple(FIRST):
201             return False
202     return True
203 #
204 # Determine whether the board is full
205 #
206 def is_full():
207     'Confirm all the places are not empty'
208     for i in range(3):
209         for j in range(3):
210             if board[i][j]==OPEN:
211                 return False
212     return True
213 #
214 # Determine whether a draw has occurred
215 #
216 def is_draw():
217     'Check wheter board is draw'
218     if is_win_simple(FIRST):
219         return False
220     if is_win_simple(SECOND):
221         return False
222     if not is_full():
223         return False
224     return True
```

Program 15-5 Tic-tac-toe program, example (Part 5: Board testing functions 1)

```

225 #
226 #_Second_board_testing_function,_which_tests_the_victory_determination
227 #
228 def test_board2():
229     'The_second_test_program_of_the_board'
230     init_board()
231     board[0][0]=FIRST
232     board[1][0]=FIRST
233     board[2][0]=FIRST
234     print(show_board())
235     print("HORIZONTAL,FIRST:",check_board_horizontal(FIRST))
236     print("HORIZONTAL,SECOND:",check_board_horizontal(SECOND))
237     print("VERTICAL,FIRST:",check_board_vertical(FIRST))
238     print("VERTICAL,SECOND:",check_board_vertical(SECOND))
239     init_board()
240     board[0][0]=SECOND
241     board[1][0]=SECOND
242     board[2][0]=SECOND
243     print(show_board())
244     print("HORIZONTAL,FIRST:",check_board_horizontal(FIRST))
245     print("HORIZONTAL,SECOND:",check_board_horizontal(SECOND))
246     print("VERTICAL,FIRST:",check_board_vertical(FIRST))
247     print("VERTICAL,SECOND:",check_board_vertical(SECOND))
248
249     init_board()
250     board[0][0]=FIRST
251     board[0][1]=FIRST
252     board[0][2]=FIRST
253     print(show_board())
254     print("HORIZONTAL,FIRST:",check_board_horizontal(FIRST))
255     print("HORIZONTAL,SECOND:",check_board_horizontal(SECOND))
256     print("VERTICAL,FIRST:",check_board_vertical(FIRST))
257     print("VERTICAL,SECOND:",check_board_vertical(SECOND))
258     init_board()
259     board[0][0]=SECOND
260     board[0][1]=SECOND
261     board[0][2]=SECOND
262     print(show_board())
263     print("HORIZONTAL,FIRST:",check_board_horizontal(FIRST))
264     print("HORIZONTAL,SECOND:",check_board_horizontal(SECOND))
265     print("VERTICAL,FIRST:",check_board_vertical(FIRST))
266     print("VERTICAL,SECOND:",check_board_vertical(SECOND))
267
268     init_board()
269     board[0][0]=FIRST
270     board[1][1]=FIRST

```

```
271     board[2][2]=FIRST
272     print(show_board())
273     print("DIAGONAL_FIRST:",check_board_diagonal(FIRST))
274     print("DIAGONAL_SECOND:",check_board_diagonal(SECOND))
275     print("INV_DIAGONAL_FIRST:",check_board_inverse_diagonal(FIRST))
276     print("INV_DIAGONAL_SECOND:",check_board_inverse_diagonal(SECOND))
277     init_board()
278     board[0][0]=SECOND
279     board[1][1]=SECOND
280     board[2][2]=SECOND
281     print(show_board())
282     print("DIAGONAL_FIRST:",check_board_diagonal(FIRST))
283     print("DIAGONAL_SECOND:",check_board_diagonal(SECOND))
284     print("INV_DIAGONAL_FIRST:",check_board_inverse_diagonal(FIRST))
285     print("INV_DIAGONAL_SECOND:",check_board_inverse_diagonal(SECOND))
286
287     init_board()
288     board[0][2]=FIRST
289     board[1][1]=FIRST
290     board[2][0]=FIRST
291     print(show_board())
292     print("DIAGONAL_FIRST:",check_board_diagonal(FIRST))
293     print("DIAGONAL_SECOND:",check_board_diagonal(SECOND))
294     print("INV_DIAGONAL_FIRST:",check_board_inverse_diagonal(FIRST))
295     print("INV_DIAGONAL_SECOND:",check_board_inverse_diagonal(SECOND))
296     init_board()
297     board[0][2]=SECOND
298     board[1][1]=SECOND
299     board[2][0]=SECOND
300     print(show_board())
301     print("DIAGONAL_FIRST:",check_board_diagonal(FIRST))
302     print("DIAGONAL_SECOND:",check_board_diagonal(SECOND))
303     print("INV_DIAGONAL_FIRST:",check_board_inverse_diagonal(FIRST))
304     print("INV_DIAGONAL_SECOND:",check_board_inverse_diagonal(SECOND))
```

Program 15-6 Tic-tac-toe program, example (Part 6: Board testing functions 2)

```

305 #
306 # Third_board_testing_function, which determines whether it is a victory or draw
307 #
308 def test_board3():
309     '''The third test program of the board'''
310     init_board()
311     board[0][0] = FIRST
312     board[1][0] = FIRST
313     board[2][0] = SECOND
314     board[0][1] = SECOND
315     board[1][1] = SECOND
316     board[2][1] = FIRST
317     board[0][2] = FIRST
318     board[1][2] = FIRST
319     board[2][2] = SECOND
320     print(show_board())
321     print("HORIZONTAL_FIRST:", check_board_horizontal(FIRST))
322     print("HORIZONTAL_SECOND:", check_board_horizontal(SECOND))
323     print("VERTICAL_FIRST:", check_board_vertical(FIRST))
324     print("VERTICAL_SECOND:", check_board_vertical(SECOND))
325     print("DIAGONAL_FIRST:", check_board_diagonal(FIRST))
326     print("DIAGONAL_SECOND:", check_board_diagonal(SECOND))
327     print("INV_DIAGONAL_FIRST:", check_board_inverse_diagonal(FIRST))
328     print("INV_DIAGONAL_SECOND:", check_board_inverse_diagonal(SECOND))
329     print("IS_WIN_SIMPLE_FIRST", is_win_simple(FIRST))
330     print("IS_WIN_SIMPLE_SECOND", is_win_simple(SECOND))
331     print("IS_WIN_ACTUAL_FIRST", is_win_actual(FIRST))
332     print("IS_WIN_ACTUAL_SECOND", is_win_actual(SECOND))
333     print("IS_FULL", is_full())
334     print("IS_DRAW", is_draw())
335
336     init_board()
337     board[0][0] = FIRST
338     board[1][0] = SECOND
339     board[2][0] = FIRST
340     board[0][1] = SECOND
341     board[1][1] = FIRST
342     board[2][1] = OPEN
343     board[0][2] = FIRST
344     board[1][2] = OPEN
345     board[2][2] = SECOND
346     print(show_board())
347     print("HORIZONTAL_FIRST:", check_board_horizontal(FIRST))
348     print("HORIZONTAL_SECOND:", check_board_horizontal(SECOND))
349     print("VERTICAL_FIRST:", check_board_vertical(FIRST))
350     print("VERTICAL_SECOND:", check_board_vertical(SECOND))

```

```

351     print("DIAGONAL_FIRST:", check_board_diagonal(FIRST))
352     print("DIAGONAL_SECOND:", check_board_diagonal(SECOND))
353     print("INV_DIAGONAL_FIRST:", check_board_inverse_diagonal(FIRST))
354     print("INV_DIAGONAL_SECOND:", check_board_inverse_diagonal(SECOND))
355     print("IS_WIN_SIMPLE_FIRST", is_win_simple(FIRST))
356     print("IS_WIN_SIMPLE_SECOND", is_win_simple(SECOND))
357     print("IS_WIN_ACTUAL_FIRST", is_win_actual(FIRST))
358     print("IS_WIN_ACTUAL_SECOND", is_win_actual(SECOND))
359     print("IS_FULL", is_full())
360     print("IS_DRAW", is_draw())
361
362     init_board()
363     board[0][0] = SECOND
364     board[1][0] = FIRST
365     board[2][0] = SECOND
366     board[0][1] = FIRST
367     board[1][1] = SECOND
368     board[2][1] = FIRST
369     board[0][2] = SECOND
370     board[1][2] = OPEN
371     board[2][2] = FIRST
372     print(show_board())
373     print("HORIZONTAL_FIRST:", check_board_horizontal(FIRST))
374     print("HORIZONTAL_SECOND:", check_board_horizontal(SECOND))
375     print("VERTICAL_FIRST:", check_board_vertical(FIRST))
376     print("VERTICAL_SECOND:", check_board_vertical(SECOND))
377     print("DIAGONAL_FIRST:", check_board_diagonal(FIRST))
378     print("DIAGONAL_SECOND:", check_board_diagonal(SECOND))
379     print("INV_DIAGONAL_FIRST:", check_board_inverse_diagonal(FIRST))
380     print("INV_DIAGONAL_SECOND:", check_board_inverse_diagonal(SECOND))
381     print("IS_WIN_SIMPLE_FIRST", is_win_simple(FIRST))
382     print("IS_WIN_SIMPLE_SECOND", is_win_simple(SECOND))
383     print("IS_WIN_ACTUAL_FIRST", is_win_actual(FIRST))
384     print("IS_WIN_ACTUAL_SECOND", is_win_actual(SECOND))
385     print("IS_FULL", is_full())
386     print("IS_DRAW", is_draw())

```

Program 15-7 Tic-tac-toe program example (Part 7: Game record-related functions)

```

387  #
388  # Log_replay
389  #
390  def replay_log(log):
391      '''Replay a game log. It shows replay on screen with print() function'''
392      init_board()
393      init_turn()
394      print(show_board())
395      for m in log:
396          if len(m) == 2:
397              print(show_turn(), "is the current turn")
398              print(set_board(m[0], m[1], turn))
399              print(show_board())
400              print("IS_WIN", turn, ": ", is_win_actual(turn))
401              change_turn()
402          else:
403              print("RESULT_IN_LOG:", m[0])
404              print("IS_WIN_FIRST:", is_win_actual(FIRST))
405              print("IS_WIN_SECOND:", is_win_actual(SECOND))
406              print("IS_DRAW:", is_draw())
407  #
408  # Log_test
409  #
410  def test_log():
411      'Test replay of logs'
412      print("LOG1")
413      replay_log(log1)
414      print("LOG2")
415      replay_log(log2)
416      print("LOG3")
417      replay_log(log3)
418  #
419  # Test_all
420  #
421  def test_all():
422      'Do all the test programs'
423      test_turn()
424      test_board1()
425      test_board2()
426      test_board3()
427      test_log()

```

Program 15-8 Tic-tac-toe program, example (Part 8: The play() function and the main program)

```

428 #
429 #_Actual_gameplay
430 #
431 def play():
432     '''Conduct_an_actual_tic-tac-toe_game_interactively_on_terminal'''
433     init_turn()
434     init_board()
435     print(show_board())
436     #_Create_an_empty_list_for_the_game_record.
437     #_Declare_it_as_a_global_variable_if_you_want_to_access_it_outside_of_play()
438     #_global_log
439     log = []
440     while True:
441         print(show_turn(), "is the current turn")
442         while(True):
443             row = int(input("Input the number of row you want to place:"))
444             column = int(input("Input a number of column:"))
445             result = set_board(row, column, turn)
446             print(result)
447             if result == "OK":
448                 break
449             print("Inadequate value(s), try again")
450             # Add a turn to the log here (outside of the inner while)
451             # Additional code required here
452             #
453             print(show_board())
454             if is_draw():
455                 print("Game is draw")
456                 #Add the game result (a draw) to log here.
457                 break
458             if is_win_actual(turn):
459                 print(show_turn(), "won the game")
460                 #Add the game result (current player's win) to log here.
461                 break
462             change_turn()
463             #This is a replay of the game
464             #Currently the log is empty, so determine victory, and process
465             if len(log)>0:
466                 replay_log(log)
467             else:
468                 print("Game log was not recorded")
469                 if __name__ == '__main__':
470                     print('Tic-Tac-Toe')

```

3) Testing the program

After reading the above program and running it in the Python shell, run the test functions from the shell to see how the program works. The test functions provided are as follows, in order from top to bottom.

```
test_turn()
test_board1()
test_board2()
test_board3()
test_log()
test_all()
```

4) Running the program

After running the above program, call the play() function from the Python shell and try playing tic-tac-toe.

```
play()
```

Exercise 15-2 Relationship of functions in tic-tac-toe program

Extract defined functions in the tic-tac-toe program, and make a spreadsheet on the relationship of functions as shown in the following figure.

- Make a table having function names in the 1st row and column,
- Mark cells with ‘↑’ whose column functions are called by the function shown in the row.

By arranging rows and columns appropriately, marks can be placed lower than the diagonal line.

	function 1	function 2	function 3
function 1			
function 2	↑		
function 3	↑	↑	

Exercise 15-3 Getting the game record

Extend the above program to collect the game record of the game in the play() function. You can also replay the game record after the winner is determined.

15.6 Test of skills

Using the methods you have learned so far, try the following as a test of your skills.

- Create a GUI-based tic-tac-toe game instead of a CUI based one, using tkinter.
- By using classes, implement functions to control the turn, the board, the game record, etc. as methods in the classes.
- Extend the game to be played by a computer on one side of the board, rather than by two humans.
- Develop a similar program for the game of Reversi instead of tic-tac-toe.

15.7 Various topics related to program development

15.7.1 What you can understand from a test

Computer programs usually have to work properly in a virtually infinite number of cases. For example, the number of possible games of tic-tac-toe is quite large. For this reason, you must consider the following points concerning tests:

- It is easy to see that **a program that does not pass the test has a mistake in it**; however,
- you must remember that **if a program passes a test, it does not guarantee that it will run properly in all cases where it is expected to have passed the test.**

It is easier to test component functions than it is to test their combined functions. You can build more confidence in your skill at using complex functions by building them with correctly working components.

15.7.2 Refactoring

There are two ways in which a program can be improved, as below

- Enhancing the functionality of the program
- Maintaining the functionality of the program, but rearranging how it is implemented in order to make it easier to maintain and extend.

The latter kind of improvement is called “**refactoring**.” An example of this is reprogramming your tic-tac-toe program using classes. There are several reasons why refactoring is necessary.

- Programs are used for a long time, so they must be easy to maintain.
- Also, the developers of the program may be replaced.
- There is a constant demand for additional functionality in programs.

15.7.3 The V-model of software development

In the first half of the development of a program, even a small example like the tic-tac-toe program you made above, the requirements of the final product (specifications) are clear. Then, you flesh out the specifics of the program step by step, including the functions to be implemented. In the second half of development, you repeatedly perform tests on non-interdependent functions in sequence, which eventually leads to the conclusion of programming after many iterations.

This process is represented by a V-shape as shown in the figure below, and is called the V-model of software development.

Because of the V-shape structure, the distance from design to implementation and testing is much greater in the upper part of the V-shape. This means that inappropriate design in the upper part of the V takes longer to be discovered in implementation and testing, and requires more diligent reworking.

There are two possible directions for successful software development detailed below. The latter is called agile development.

- Define required specifications, and reduce reworking
- Narrow down the specifications and develop quickly, then add features if necessary.

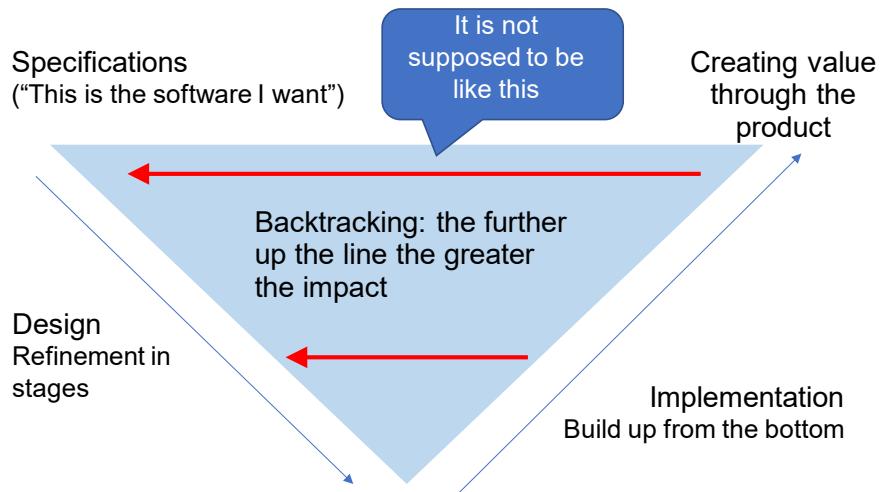


Figure 15-5 The V-Model of Software Development

16. Academic Use of Python

16.1 Learning goals of this chapter

One of the reasons why Python has attracted so much attention is that it offers a wide range of libraries suitable for numerical computation, as well as for other academic applications. We will use the following three libraries in this chapter to learn the basics of working with data (in NumPy and pandas), as well as the basics of graphing (in Matplotlib).

Each of them is a quite sophisticated package, and you need to have some expertise in the fields in which these packages are applied in order to fully utilize them, so you will learn only the basics here.

1. NumPy: A basic package for numerical computation in the field of science and technology
SciPy: A library for more advanced numerical computations
2. Matplotlib: A package for plotting data on graphs
3. pandas: a data analysis package

These are interrelated, as shown in the figure below.

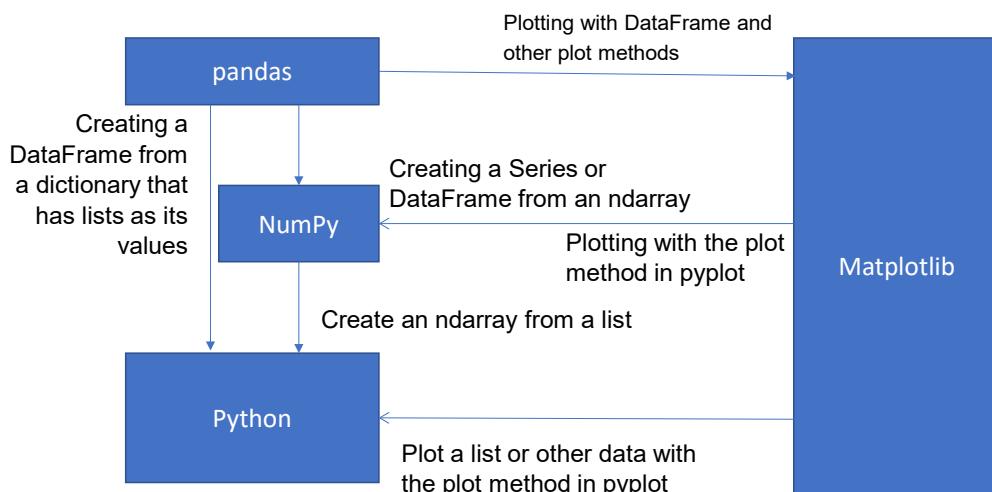


Figure 16-1 The relationship between NumPy, Matplotlib and pandas

16.2 Using a custom name when importing

The following custom names are often used for importing packages such as NumPy, Pandas, Matplotlib. You will use these custom names in this text.

```

import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
  
```

16.3 NumPy

Python is a slow programming language, but NumPy is written in C, and can perform vector and matrix operations very quickly.

16.3.1 Generating multi-dimensional arrays

While Python uses lists to group data together, NumPy uses its own data format, the ndarray (aka array).

1) Generating from a list

```
import numpy as np  
  
data1 = [1, 2, 3]  
  
arr1 = np.array(data1) # 1-dimensional data  
  
data2 = [[1,2,3],[4,5,6]]  
  
arr2 = np.array(data2)
```

2) Create an array in which all elements are zero

```
np.zeros(5) # A 1D array of with 5 elements  
  
array([0., 0., 0., 0., 0.])  
  
np.zeros((2,2)) # A 2D array of with a size of (2,2); note the double  
parentheses ()  
  
array([[0., 0.],  
       [0., 0.]])  
  
a = np.array([[1,2,3],[4,5,6]])  
  
np.zeros_like(a) # Same size as array a  
  
array([[0, 0, 0],  
       [0, 0, 0]])
```

An array consisting only of 1's can be created using ones and ones_like.

16.3.2 ndarray attributes

You can read up on your own about the following attributes of ndarrays.

- ndim : ndarray dimension
- shape: ndarray size
- dtype: Data type

```
import numpy as np
```

```
arr2 = np.array([[1,2,3],[4,5,6]]  
arr2.ndim  
2  
arr2.shape  
(2,3)  
arr2.dtype  
dtype('Int32')
```

Note that while Python's integer types have no limit on the number of digits, ndarray uses a fixed-length type that allows fast operations to be performed in order to speed up computation.

16.3.3 Accessing ndarray elements

The elements of an ndarray can be accessed using [] in the same way as a list. These ndarrays also start at an index of 0.

```
arr1 = np.array([1,2,3])  
arr1[0]  
1  
arr1[1] = 1  
arr1  
array([1,1,3])
```

For multi-dimensional arrays you can also use [,] notation instead of [][].

```
arr2[0][0]  
arr2[0,0]
```

16.3.4 Slicing

ndarrays can be sliced in the same manner as lists can.

```
arr1[2:]  
array([3])
```

Multi-dimensional arrays use the following notation: [:,:]

```
arr2[0:2,0:2]  
array([1,2][4,5])
```

Note The result of slicing an ndarray is not a “copy,” but a reference to a part of the original ndarray. If you assign a scalar value to a slice, it will be assigned to all elements.

16.3.5 ndarray operations

ndarray data can be used to perform arithmetic operations, powers, comparisons, and so on. These operations are iterable over all elements in the ndarray.

Matrix products use the `@` operator.

The value is applied to all the elements for scalar operations.

```
arr1 = np.array([1,2,3])
arr1*2
array([2,4,6])
arr1 + 1
array([2,3,4])
```

16.3.6 Extraction of elements satisfying the conditions

You can extract the elements that satisfy the conditions in the following way.

```
arr1 = np.array([1,2,3,4,5])
cond = arr1 > 2      # Generate an array of elements that satisfy the
conditions
cond
array([False, False, True, True, True])
arr1[cond]           # Slice based on the defined conditions
array([3, 4, 5])
```

16.3.7 Matrix Calculations

Numpy makes it easy to perform mathematical matrix calculations on ndarrays.

- Matrix transposition (swapping rows and columns)
We will use the `T` attribute of ndarray.
- Matrix product
We will use the `@` operator.
- Using the linalg (linear algebra) module: `numpy.linalg` (or `np.linalg` if you imported numpy with the `np` alias) defines the following matrix functions.
 - `diag` (diagonal elements),
 - `trace` (sum of diagonal elements),
 - `det` (determinant),
 - `eig` (eigenvalue),
 - `inv` (inverse),
 - `solve` (to solve a linear equation)

16.3.8 Random numbers

Numpy allows you to generate random numbers in bulk.

- seed: sets the initial value for random number generation.
- rand: generates uniformly continuous random numbers.
- randn: generates random numbers that follow a standard normal distribution.
- randint: generates random numbers in a given range.

Here is an example of how to use it.

- `np.random.rand(10)`
Generates 10 floating-point random numbers with values between 0 and 1
- `np.random.randn(5,5)`
Generates random numbers that follow a standard normal distribution as a two-dimensional array of size (5,5)
- `np.random.permutation([1,2,3,4,5])`
Generates a random permutation of the list [1,2,3,4,5]. range() and ndarray can be specified as arguments. For multi-dimensional arrays, only the first index is replaced.
- `np.random.randint(2,size=10)`
Generates an integer random number in range(0,2) with a size of 10. Since we are able to provide lower and upper limits, The size of the array can be specified using “size=”

16.4 Matplotlib

16.4.1 backend: graph output environment

Matplotlib allows you to choose how to output the graph. In this section, we see how to use tkagg, which is a tkinter-based environment for IDLE.

- In Matplotlib, the environment that actually outputs the graph is called a backend. There are various backends available.
 - tkagg is a backend that uses Tkinter to output graphs.
 - In the IDLE environment, it is specified using the use() function after importing matplotlib.
- ```
import matplotlib
matplotlib.use('tkagg')
```
- The use() function must be specified before importing the matplotlib.pyplot plotting module.
  - In IPython and Jupyter Notebook (which uses IPython), before using matplotlib, you can specify the following, depending on the backend you want to use.
- ```
%matplotlib notebook
%matplotlib tk
```

16.4.2 Text output in Japanese

- The standard matplotlib font does not support Japanese characters, so they will be displayed as boxes (□).
- The ttc font can now be used in matplotlib version 3.1 or later. If you are using this version or a newer one, you do not need to install additional fonts ¹.
- There are several ways to specify fonts, but here we show how to specify them all at once in the program.
- If you have installed additional fonts, first delete the fontList.json in the .matplotlib folder in the user's folder if it is old.
- Usage of fonts for OS in matplotlib is shown in Program 16-1, and execution result is shown in Figure 16-2.
- For Mac user, comment out line 7, and uncomment line 10 in Program 16-1.

Program 16-1 matplotlib example (use_matplotlib_outline.py)

Raw	Source Code
1	import matplotlib
2	# Set tkinter as the output destination before importing pyplot
3	matplotlib.use('tkagg')
4	import matplotlib.pyplot as plt
5	# Enable matplotlib to display Japanese characters.
6	# Yu Gothic can be used in matplotlib version 3.1 or later
7	matplotlib.rcParams['font'] = {'family': 'Yu Gothic'}
8	# For Mac User, try the following instead of the above line
9	# matplotlib.rcParams['font'] = {'family': 'Hiragino Maru Gothic Pro'}
10	# The following is an example plot
11	data = [1,2,3]
12	plt.plot(data)
13	plt.title('タイトル')
14	plt.show()

¹ The following example uses Yu Gothic, but Yu Mincho, MS Gothic, MS Mincho, etc. can also be used.

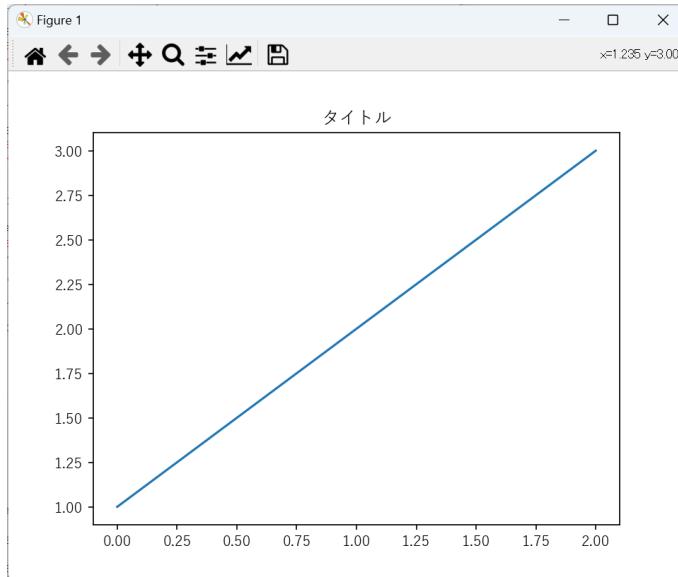


Figure 16-2 Execution of Program 16-1

16.4.3 Setting the Title, Axis Labels, and Linestyle

- The function to set the title of the graph is `title`.
- The function to set the x-axis labels is `xlabel`.
- The function to set the y-axis labels is `ylabel`.
- The linestyle can be specified as an argument of the `plot` function.
 - By specifying the color, and linestyle, and marker as strings
 - By specifying the color, linestyle, linewidth, etc. as arguments.

- Example (the relevant part only)

```
plt.plot([1,2,3], 'k-') # A black solid line  
plt.plot([2,3,4], 'r--') # A red dashed line  
plt.plot([3,4,5], 'b--o') # A blue dashed line with circular markers (O)  
plt.title('Title')  
plt.xlabel('Horizontal Axis')  
plt.ylabel('Vertical Axis')  
plt.show()
```

16.4.4 Example

1) use_matplotlib.py

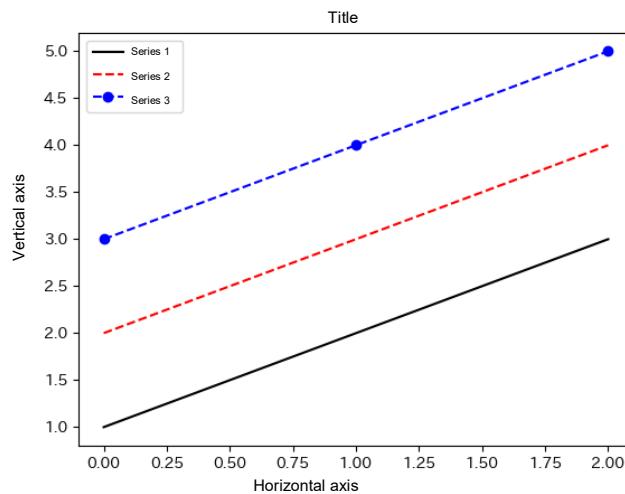


Figure 16-3 Example of Matplotlib usage

Program 16-2 use_matplotlib.py

Row	Source code
1	#
2	#_The_basic_way_to_use_matplotlib
3	#
4	import matplotlib
5	#
6	#_set_tkinter_to_use_(as_the_output_destination)_before_importing_pyplot
7	#
8	matplotlib.use('tkagg')
9	import matplotlib.pyplot as plt
10	#
11	#_Enable_matplotlib_to_display_Japanese_characters.
12	#_uncomment_one_apropriate_for_your_environment
13	#
14	#_For_Windows
15	matplotlib.rcParams['font', **{'family': 'YuGothic'})
16	#_For_Campus_PC_Terminal
17	#matplotlib.rcParams['font', **{'family': 'IPAPGothic'})
18	#_For_macOS
19	#matplotlib.rcParams['font', **{'family': 'Hiragino_Maru_Gothic_Pro'})
20	#
21	#_Draw_a_line_graph_with_three_lines
22	#
23	plt.plot([1,2,3], 'k-', label='Series_1')
24	plt.plot([2,3,4], 'r--', label='Series_2')
25	plt.plot([3,4,5], 'b--o', label='Series_3')
26	#
27	plt.title('Title')
28	plt.xlabel('Horizontal_Axis_')
29	plt.ylabel('Vertical_Axis_')
30	plt.legend() #_Legend
31	plt.show()

2) Drawing a scatter plot

A scatter plot can be drawn by giving the x-axis data and y-axis data to the scatter function of pyplot.

- use_matplotlib_scatter.py

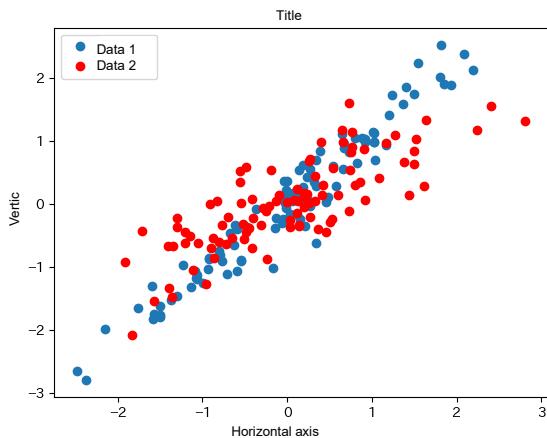


Figure 16-4 Drawing a scatter plot

Program 16-3 use_matplotlib_scatter.py

Row	Source code
1	#
2	#_Draw_a_scatter_plot_with_matplotlib
3	#
4	import matplotlib
5	
6	matplotlib.use('tkagg')
7	import matplotlib.pyplot as plt
8	import numpy as np
9	#
10	#_Enable_matplotlib_to_display_Japanese_characters.
11	#_uncomment_one_apropriate_for_your_environment
12	#
13	#_For_Windows
14	matplotlib.rcParams['font', **{'family': 'Yu_Gothic'})
15	#_For_Campus_PC_Terminal
16	#matplotlib.rcParams['font', **{'family': 'IPAPGothic'})
17	#_For_macOS
18	#matplotlib.rcParams['font', **{'family': 'Hiragino_Maru_Gothic_Pro'})
19	#
20	#_Create_random_data
21	#
22	datax=np.random.randn(100)
23	datay=datax+np.random.randn(100)*0.3
24	#
25	#_Draw_a_scatter_plot.
26	#
27	plt.scatter(datax,datay,label='Data1')
28	#
29	#_Create_another_set_of_data

```
30 #_
31 datax_=np.random.randn(100)
32 datay_=0.6*datax_+np.random.randn(100)*0.4
33 #
34 #Specify the color, then create a scatter plot
35 #
36 plt.scatter(datax,datay,color='red',label='Data2')
37 #
38 #Fill in the title, axis labels, and legend
39 #
40 plt.title('Title')
41 plt.xlabel('Horizontal Axis ')
42 plt.ylabel('Vertical Axis ')
43 plt.legend()
44 #
45 #Display
46 #
47 plt.show()
```

•

3) Drawing a Histogram

You can draw a histogram by feeding the data for it into the hist function of pyplot. The number of bars is automatically adjusted, but it can also be specified.

use_matplotlib_hist.py

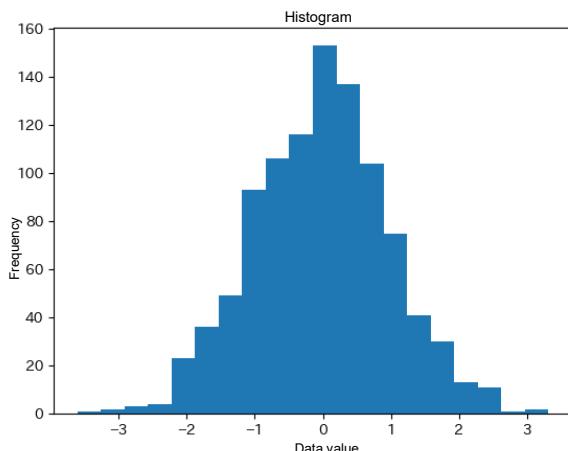


Figure 16-5 Drawing a Histogram

Program 16-4 use_matplotlib_hist.py

Row	Source code
1	#
2	#_Draw_a_histogram_with_matplotlib
3	#
4	import matplotlib
5	#
6	#_Set_tkinter_as_the_output_destination_before_importing_pyplot
7	#
8	matplotlib.use('tkagg')
9	import matplotlib.pyplot as plt
10	import numpy as np
11	#
12	#_Enable_matplotlib_to_display_Japanese_characters.
13	#_uncomment_one_apropriate_for_your_environment
14	#
15	#_For_Windows
16	matplotlib.rcParams['font', **{'family': 'YuGothic'})
17	#_For_Campus_PC_Terminal
18	#matplotlib.rcParams['font', **{'family': 'IPAPGothic'})
19	#_For_macOS
20	#matplotlib.rcParams['font', **{'family': 'Hiragino_Maru_Gothic_Pro'})
21	#
22	#_Create_a_histogram
23	#
24	data = np.random.randn(1000)
25	plt.hist(data, bins=20)
26	#
27	#_Set_the_title_and_axis_labels
28	#
29	plt.title('Histogram')
30	plt.xlabel('Value of Data')
31	plt.ylabel('Data Frequency')
32	#
33	#_Display
34	#
35	plt.show()

4) Drawing Multiple Graphs

Matplotlib allows you to draw multiple graphs side by side in the following manner.

- Obtain a Figure object using pyplot's figure function.
- Add a subplot to the Figure object with pyplot's add_subplot function. Save the result to a variable.
- Adjust the spacing of the subplots with pyplot's subplots_adjust function.

- Draw each subplot with the plot, scatter, and hist functions.
- Add the title and axis labels with set_title, set_xlabel, and set_ylabel. Make sure the function names are correct.

use_matplotlib_subplot.py

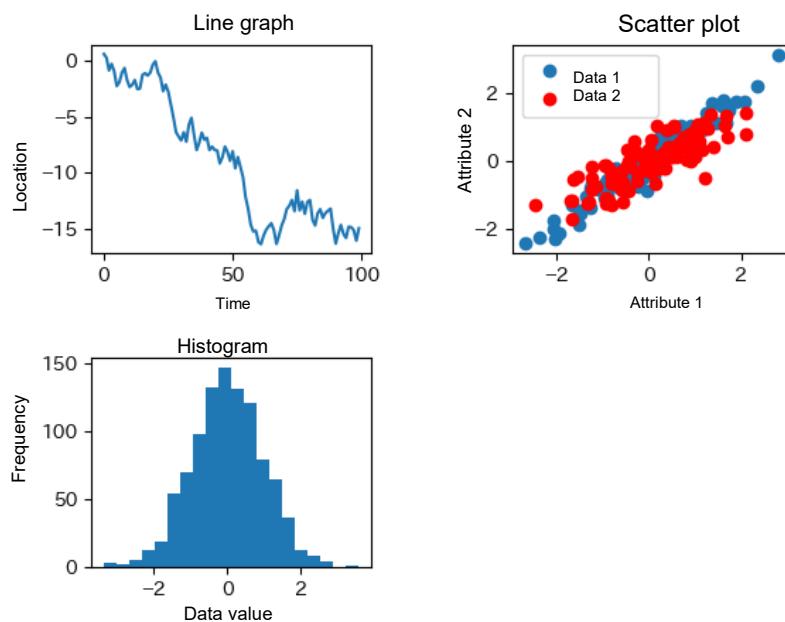


Figure 16-6 Drawing multiple graphs

Program 16-5 use_matplotlib_subplot.py

Row	Source code
1	#
2	#_Example_using_subplot
3	#
4	import matplotlib
5	matplotlib.use('tkagg')
6	import matplotlib.pyplot as plt
7	import numpy as np
8	#
9	#_Enable_matplotlib_to_display_Japanese_characters.
10	#_uncomment_one_apropriate_for_your_environment
11	#
12	#_For_Windows
13	matplotlib.rc('font', **{'family': 'Yu_Gothic'})
14	#_For_Campus_PC_Terminal
15	#matplotlib.rc('font', **{'family': 'IPAPGothic'})
16	#_For_macOS
17	#matplotlib.rc('font', **{'family': 'Hiragino_Maru_Gothic_Pro'})
18	#
19	#_Create_3_subplots,_and_adjust_the_spacing

```
20 #  
21 fig=plt.figure()  
22 ax1=fig.add_subplot(2,2,1)  
23 ax2=fig.add_subplot(2,2,2)  
24 ax3=fig.add_subplot(2,2,3)  
25 plt.subplots_adjust(hspace=0.5,wspace=0.5)  
26 #  
27 #First, output a line graph  
28 #  
29 data=np.random.randn(100).cumsum()  
30 ax1.plot(data)  
31 ax1.set_title('Line Graph')  
32 ax1.set_xlabel('Time')  
33 ax1.set_ylabel('Place')  
34 #  
35 #Second, output a scatter plot  
36 #  
37 datax=np.random.randn(100)  
38 datay=datax+np.random.randn(100)*0.3  
39 ax2.scatter(datax,datay,label='Data1')  
40  
41 datax=np.random.randn(100)  
42 datay=0.6*datax+np.random.randn(100)*0.4  
43 ax2.scatter(datax,datay,color='red',label='Data2')  
44  
45 ax2.set_title('Scatter Plot')  
46 ax2.set_xlabel('Attribute1')  
47 ax2.set_ylabel('Attribute2')  
48 ax2.legend()  
49  
50 #  
51 #Third, output a histogram  
52 #  
53 data=np.random.randn(1000)  
54 ax3.hist(data,bins=20)  
55  
56 ax3.set_title('Histogram')  
57 ax3.set_xlabel('Value of Data')  
58 ax3.set_ylabel('Data Frequency')  
59  
60 #  
61 #Display the graphs  
62 #  
63 plt.show()
```

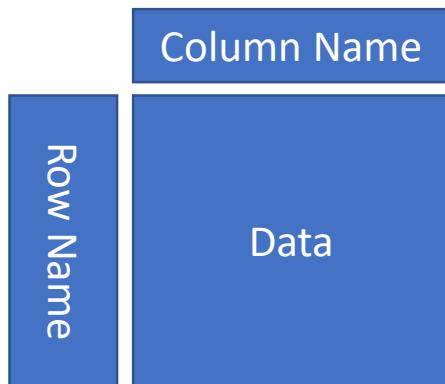
16.5 pandas

16.5.1 Dataframe

The following are Pandas-specific data formats.

- One-dimensional Series
- Two-dimensional DataFrame

A DataFrame has a row name (index) and a column name (column).



16.5.2 Create a DataFrame

1) Create from an array in numpy

```
import numpy as np  
import pandas as pd  
  
d = np.array([[1,2,3],[4,5,6],[7,8,9]])  
df = pd.DataFrame(d,columns=['a','b','c'])  
  
df  
  
   a   b   c  
0  1   2   3  
1  4   5   6  
2  7   8   9
```

The column and row names can be found using:

```
df.columns  
df.index
```

respectively.

2) Create from a dictionary where the values are lists.

```
df = pd.DataFrame({'a': [1,4,7], 'b':[2,5,8], 'c':[3,6,9]})

df
   a  b  c
0  1  2  3
1  4  5  6
2  7  8  9
```

A dictionary is a Python data type that consists of a set of key-value pairs.

```
dic = {'a':1, 'b':2, 'c':3}
```

You can search for values using the keys.

```
dic['a']
1
```

16.5.3 Importing csv files

- You can create a DataFrame by reading data A a spreadsheet saved as a csv file.

```
df = pd.read_csv("file name")
```

- The first row is treated as the column name.

- If you want to read all the data, specify the following options.

```
header = None or names = [list of column names]
```

- To read a file containing Japanese characters on Windows, specify the Japanese character encoding.

```
encoding = 'SHIFT-JIS'
```

- If you use Japanese character encoding for column names, an error will occur when specifying data in column names.

- sample.csv is show below.

Program 16-6 read the data with the follow steps (use_read_csv.py)

1. Import numpy module.
2. Import pandas module.
3. Import os module.
4. show the current working folder, and then get folder path. If sample.csv is located in the shown folder, just type '.', otherwise give the folder path.
`folderpath_= input("Enter_folder_path: ")`
5. Use os.chdir to change to the folder with the csv file.

```
os.chdir(folderpath)
```

- Import the csv file

```
df = pd.read_csv("sample.csv")
```

- Show the read data and their summary with the following:

```
print(df)
```

```
print(df.describe())
```

Note: pd.read_csv does not seem to be able to handle Japanese file names correctly.

Table 16-1 sample.csv

ID	Japanese	English	Mathematics	Science	Social Studies	
A	91	69	100	82		94
B	80	60	45	52		46
C	92	92	76	73		97
D	58	50	60	71		77
E	58	75	96	96		94
F	92	89	86	82		74
G	97	87	59	55		56
H	62	73	52	60		74
I	73	85	41	49		75
J	61	61	49	51		63
K	49	56	58	63		85
L	42	50	56	59		78
M	52	66	50	49		43
N	88	72	52	64		48
O	72	75	56	54		80
P	94	90	61	58		67
Q	95	85	72	68		43
R	70	85	68	62		81
S	74	85	96	96		53
T	65	53	64	67		75

By executing the program we obtain the following:

ID	Japanese	English	Mathematics	Science	Social Studies	Total
0 A	91	69	100	82	94	436
1 B	80	60	45	52	46	283
2 C	92	92	76	73	97	430
3 D	58	50	60	71	77	316
4 E	58	75	96	96	94	419
5 F	92	89	86	82	74	423
6 G	97	87	59	55	56	354

7	H	62	73	52	60	74	321
8	I	73	85	41	49	75	323
9	J	61	61	49	51	63	285
10	K	49	56	58	63	85	311
11	L	42	50	56	59	78	285
12	M	52	66	50	49	43	260
13	N	88	72	52	64	48	324
14	O	72	75	56	54	80	337
15	P	94	90	61	58	67	370
16	Q	95	85	72	68	43	363
17	R	70	85	68	62	81	366
18	S	74	85	96	96	53	404
19	T	65	53	64	67	75	324
		Japanese	English	Mathematics	Science	Social Studies	Total
count		20.000000	20.000000	20.000000	20.000000	20.000000	20.000000
mean		73.250000	72.900000	64.850000	65.550000	70.150000	346.700000
std		17.149114	14.164076	17.547754	14.195904	17.141132	53.425896
min		42.000000	50.000000	41.000000	49.000000	43.000000	260.000000
25%		60.250000	60.750000	52.000000	54.750000	55.250000	314.750000
50%		72.500000	74.000000	59.500000	62.500000	74.500000	330.500000
75%		91.250000	85.000000	73.000000	71.500000	80.250000	378.500000
max		97.000000	92.000000	100.000000	96.000000	97.000000	436.000000

Program 16-6 use_read_csv.py

Row	Source code
1	import numpy as np
2	import pandas as pd
3	import os
4	#
5	# Navigate to the folder with the data
6	#
7	# pandas does not handle Japanese file names well
8	#
9	print("Current folder: "+os.getcwd())
10	folderpath=input("Enter folder path:")
11	os.chdir(folderpath)
12	df=pd.read_csv("sample.csv")
13	#
14	# Sum horizontally (axis=1) and create a column called Total
15	df['Total']=df.sum(axis=1,numeric_only=True)
16	# Display the DataFrame df
17	print(df)
18	# Display summary statistics for DataFrame df
19	print(df.describe())

16.5.4 Display summary statistics

The describe method can be used to display summary statistics.

16.5.5 Plotting Data in Pandas

Plotting in Pandas is done by calling the plot method in the DataFrame. (use_DataFrame_plot.py)

```
df.plot()      # Line graph
df.plot.bar(stacked=True) # stacked bar graph
df.plot.scatter('Japanese','English') # Scatter plot with defined columns
df['Japanese'].plot.hist() # Histogram with defined columns
```

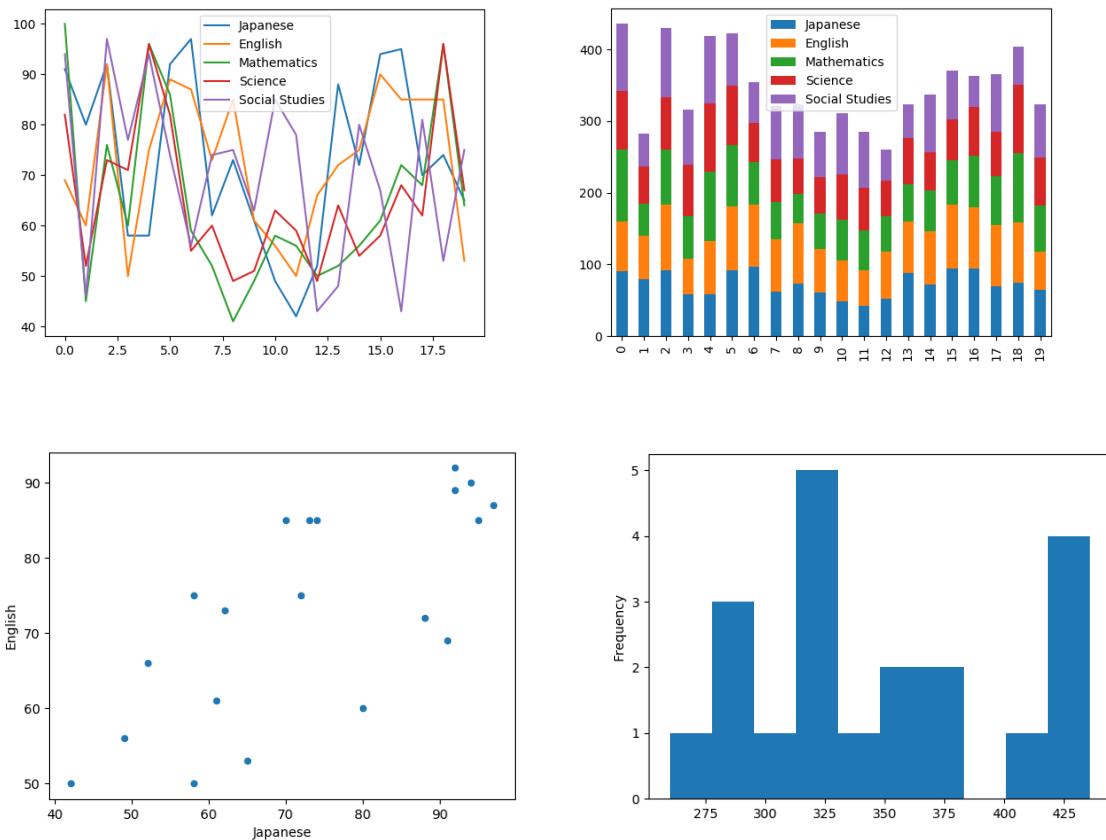


Figure 16-7 Graphing with pandas

Program 16-7 use_DataFrame_plot.py

Row	Source code
1	import numpy as np
2	import pandas as pd
3	import os
4	import matplotlib
5	matplotlib.use('tkagg')
6	import matplotlib.pyplot as plt
7	#
8	# Navigate to the folder with the data
9	#
10	# set adequate path for your environment
11	folderpath_=input("Enter folder path:")
12	os.chdir(folderpath)
13	#
14	df_=pd.read_csv("sample.csv")
15	#
16	#
17	# Line graph

```
18 #
19
20 df.plot()
21 print("Close_window_to_proceed")
22 plt.show()
23 #
24 #_Stacked_bar_graph
25 #
26 df.plot.bar(stacked=True)
27 print("Close_window_to_proceed")
28 plt.show()
29 #
30 #_Scatter_plot
31 #
32 df.plot.scatter('Japanese','English')
33 print("Close_window_to_proceed")
34 plt.show()
35 #
36 #_Sum_horizontally_(axis_=1)_and_create_a_column_called_Total
37 #_Specify_numeric_only_parameter_to_skip_ID_column.
38 df['Total']=df.sum(axis=1,numeric_only=True)
39
40 #
41 #_Histogram
42 #
43 df['Total'].plot.hist()
44 print("Close_window_to_proceed")
45 plt.show()
```

16.6 Practice task

np_matplotlib.py is a program that uses Numpy and matplotlib to draw graphs of powers of 1 to 4.

Exercise 16-1 Modify it to draw a approximation of a saw wave with sum of trigonometric functions.

In Numpy (np) you can use np.pi for pi and np.sin() for the sine function.

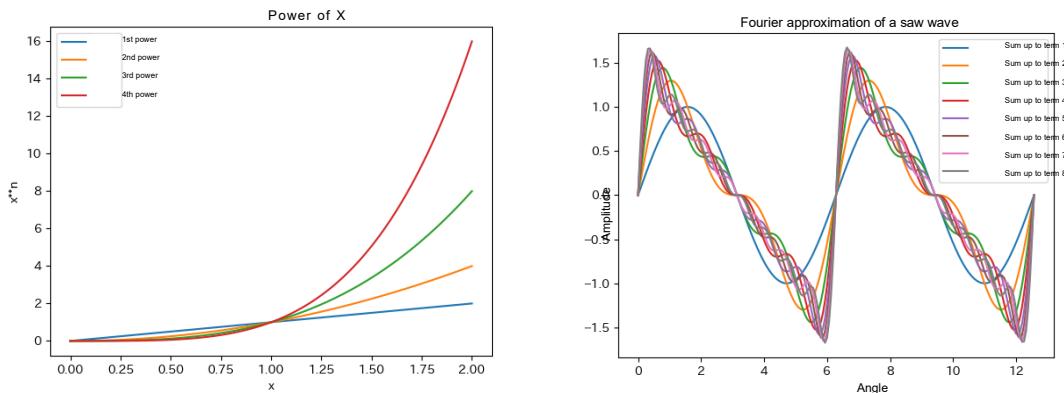


Figure 16-8 A power graph and an approximation of a sawtooth wave by summing trigonometric functions

Program 16-8 Drawing graphs of powers of 1 to 4 with Numpy and Matplotlib (use_matplotlib_power_function.py)

Row	Source code	Notes
1	# Example of plotting data in Numpy	Preparing matplotlib
2	import matplotlib	
3	matplotlib.use('tkagg')	Preparing numpy
4	import matplotlib.pyplot as plt	Setting the font in matplotlib
5	import numpy as np	
6	# For Windows	
7	matplotlib.rcParams['font', **{'family': 'Yu Gothic'}]	
8	# For Campus PC Terminal	
9	#matplotlib.rcParams['font', **{'family': 'IPAPGothic'}]	
10	# For macOS	
11	#matplotlib.rcParams['font', **{'family': 'Hiragino Maru Gothic Pro'}]	
12	#	
13	# Plot x to the 1st to 4th power	
14	#	
15	steps = 100	
16	order = 4	
17	maxx = 2	
18	#	
19	# Create a matrix with a steps row and order column with element values set to 0	
20	#	
21	dataList = np.zeros((steps, order))	
22	#	
23	# List for the legend	
24	#	
25	Legend_Label = []	

```
26 #
27 # Create a value for x in linspace
28 #
29 x=np.linspace(0,maxx,steps)
30 #
31 # For each column, calculate everything at once
32 #
33 for j in range(1,order+1):
34     dataList[:,j-1]=x**j
35     legend_label.append('Power of' + str(j))
36 #
37 # Plot
38 #
39 plt.plot(x,dataList)
40 plt.title('Power function of x')
41 plt.xlabel('x')
42 plt.ylabel('x**n')
43 plt.legend(legend_label)
44 plt.show()
```

References

- [19] Wes McKinney: Python for Data Analysis: Data Wrangling with Pandas, NumPy, and IPython, O'Reilly Media, 2nd Ed. (2017)

The tutorial pages on the following sites are helpful.

- [20] NumPy website
<http://www.numpy.org/index.html>
- [21] Pandas website
<https://pandas.pydata.org/>
- [22] Matplotlib website
<https://matplotlib.org/>
- [23] TkAgg button controls, etc. (hard to find)
https://matplotlib.org/users/navigation_toolbar.html

17. Review, and Where to Go From Here

17.1 Learning goals of this chapter

1. This is the last part of the course. In this chapter, we will look back at what we have learned so far.
2. We learned how to use the IDLE integrated environment with Python exercises. We chose IDLE because it has limited functionality and is easy to learn, but we will also learn about what else is available here.
3. We will then think about how to apply what you have learned.

17.2 Reflection

Please reflect on your learning by comparing your skills before and after this class.

- What are you now able to do?
- How was it different from your expectations before the course?
- What kind of learning objectives will you set in the future?

17.3 *Shuhari* (three stages of mastery) - “Obey, Digress, Separate”

At the end of the semester, we asked students who had taken this class for their opinions. Several of them said, “I can read Python programs now, but I don't feel like I can write them myself.” In fact, “being able to read” is a big step forward, and if you can run the program while understanding it, it will be easy to modify it a little. As you gain more experience, you will gradually be able to write your own programs.

In Japanese martial arts, we use the term *Shuhari* (lit. “Obey, Digress, Separate”). In programming, if you read the programs written by your predecessors, execute them, play around with them by changing them slightly, and apply them, you will accumulate knowledge and eventually be able to do creative programming.

17.4 Python environments

In this class, we used IDLE as an integrated Python environment because of its simple structure and ease of use for beginners. IDLE is said to be a “throw-away” environment because of its simplicity. Python, on the other hand, has a variety of usage environments.

- Jupyter Notebook and Spider are included in Anaconda.
- These environments run in IPython, a more interactive execution environment than the Python shell.
- A style of editors and command line execution suited to Python (python, IPython) is also

used.

17.5 Adding modules

One of the main features of Python is that many people have developed a variety of libraries in the language. There is a lot of information on the web and elsewhere about specific application examples, but in order to use them you need to add live modules: in Anaconda you can use the conda command to add modules that are not covered by anaconda, or the pip command if you use Python as a distribution package. In Anaconda, use the conda command, and if you are using Python as a distribution package, use the pip command to add modules.

17.6 Topics not covered in this book

Python is a programming language with a wide range of applications, but each application requires knowledge of the relevant area of application. NumPy and pandas, which were introduced in this book, cannot be used without knowledge of numerical computation and statistical processing. For this reason, we have not covered some topics that require knowledge of related fields. The following are some examples.

While the World Wide Web (WWW) is a very important area to apply one's programming skills, this requires knowledge of different programming languages such as HTML to write Webpages or SQL to manipulate databases. As such, WWW is not covered here as it can cause confusion for beginner students learning Python.

When thinking of specific things related to programming, things like the following come to mind: Python boasts a host of libraries with thorough and widely-publicized documentation and tutorials. Students should study things that align with their interests.

- Network and web-related topics
- Multimedia topics such as image processing
- Topics related to databases
- Topics related to the IoT as it pertains to microcomputer boards and electronic manufacturing
- Programming for geographical information systems
- Topics related to artificial intelligence such as machine learning

17.7 Gratitude and repayment - how to make use of what you have learned

There are many people who do carpentry at home. If you can do carpentry, you can solve problems in your home by making simple furniture and other DIY things. On the other hand, working with metal, which requires machines such as drilling machines, lathes, and milling machines, can be a bit more challenging. So, there are not many people who try to make DIY metal products.¹.

¹When I was in junior high school, me and a friend of mine whose family owned an ironworks thought about making a bicycle together. What you think that you can do depends on the environment you are in.

If you are able to program computers, not just in Python, we believe that you will be able to **look at things in a way** that says, “**I should be able to do this with a computer.**” If this is the case for you, we urge you to think about how you can contribute to society through computers and programming.

Computers, programming languages, and other software, including Python, are “other people’s creations;” they are a gift from many engineers and programmers, so to speak. If you enjoy programming, be thankful for this and try to give back.

References

We will suggest a few publications to help students continue their studies. Being able to write programs that are easy to read is a very important skill. Reference [24] teaches how to do that while also introducing various tools that help support Python programming. One of Python's most attractive features is the wealth of libraries for all sorts of applications. Reference [25] serves as a good introductory guide to these libraries. In this book, we also dealt with an example where we created voice files back in the column section of the chapter that dealt with trigonometric functions. Reference [26] covers how to handle sounds in Python and explains the acoustics knowledge and digital signal treatment methods necessary for doing so.

- [24] Al Sweigart: Beyond the Basic Stuff with Python, No Starch Press (2020)
- [25] 松田晃一：Python ライブラリの使い方 第2版, カットシステム (2023, in Japanese)
- [26] 青木直史：Python で始める音のプログラミング, オーム社 (2022, in Japanese)

18. Appendix: Useful notes on Python and IDLE

18.1 Useful notes on Python

- `help()` function: Allows you to read the description of a module or function supplied as an argument.
- `globals()`: Displays globally defined variables and other information.
- `id(x)`: Shows the identity of object x. You can check if different variables point to the same object.
- `type(x)`: Shows the type of object x. You can check what type of object is assigned to the variable.

18.2 Pay attention to file names

Do not create files with file names that are the same as modules to be imported.

Python searches for modules in a specific folder. The same folder as the file to be executed is the target of the module search. For example, if you are using the `turtle` module and you have a file named `turtle.py`, Python will incorrectly assume that this file is a module.

18.3 IDLE notes: Python shell hotkeys

- `Ctrl-C`: Stop a running program
- `Ctrl-D`: (when input in the terminal) End file
 - Note: In the shell interactive mode, this will exit the shell.
- `TAB key`: Smart indent
 - If pressed after a character, it will display auto-complete suggestions
- `ALT-P`: Go back in history (you can reuse lines you have already typed, etc. P stands for previous)
- `ALT-N`: Go forward in history (you can reuse lines you've already typed; N stands for next)
- Script execution
 - After executing a script created in the editor, the environment will be in the interactive mode. You can call functions and check global variables in the script.

18.4 IDLE notes: Editor

Hotkeys

- `Ctrl-]`: Indent the selected range
- `Ctrl-[`: Unindent the indentation of the selected range

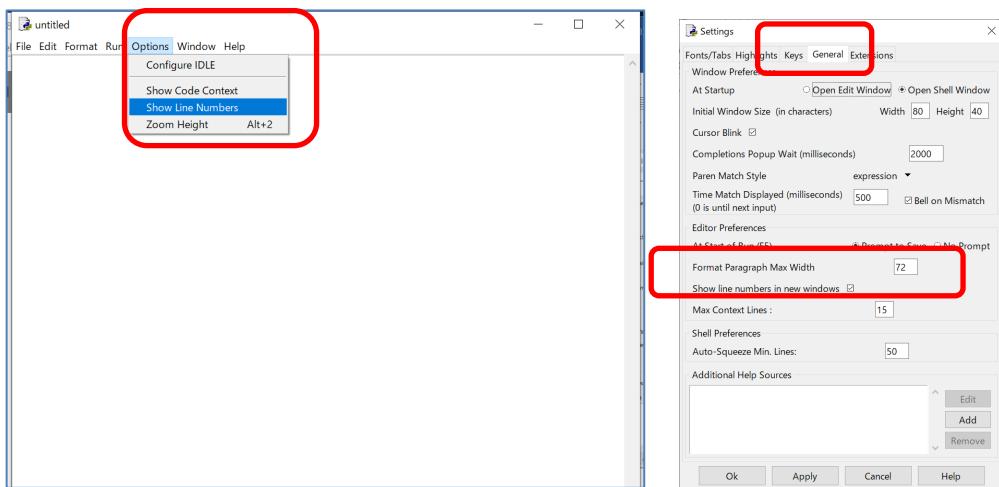
- ALT-3: Comment out the selected range
- ALT-4: Undo comment out for the selected range
- Ctrl-BS: Delete the word to the left
- Ctrl-Del: Delete the word to the right

The following hotkey operations generally available in Windows are also useful.

- Ctrl-X: Cut
- Ctrl-C: Copy
- Ctrl-V: Paste

18.4.1 Show Line Number

Since Python 3.8, the IDLE editor can show line numbers next to the source code, by selecting Show Line Number from either the Options menu, or by selecting it under the General tab in Configure IDLE menu.



Also, command line arguments can now be passed at runtime by selecting the Run ... Customized menu. (Command line arguments are not explained in this text.)

19. Appendix: How to Read Error Messages in IDLE/Python

As a program gets more complex, even a simple mistake in copying and executing the source code can result in a variety of errors. There are two ways that errors are displayed in IDLE:

- Syntax errors in the source code displayed by the IDLE editor
- Run-time errors displayed by the Python shell

Let's take a look at some of the most common errors and what they mean¹. An error occurs when the computer that interprets and executes the program is unable to continue processing. In many cases, the error occurs in a different place than the actual error caused by the programmer. You need to read error messages and think about what they mean.

19.1 Errors displayed by the IDLE editor

Syntax errors are checked before execution and displayed by the IDLE editor.

19.1.1 Example Program 1 - Missing Colon

Program 19-1 missing_colon_error.py

Row	Source code	Notes
1	#	
2	#_This_code_will_give_you_some_experience_with_errors	
3	#_There_is_no_colon_(:)_at_the_end_of_line_11	
4	#	
5	def func1(x):	
6	x=x*x	
7	return x	
8	#	
9	#_There_is_no_colon_(:)_at_the_end_of_the_next_line	
10	#	
11	def func2(y,x)	
12	xx=func1(x)	
13	return y+xx	
14		
15	#_Main_from_here	
16	a=1	
17	b=2	
18	print(a,b,func2(a,b))	You need to use a colon (:) at the end here

In this example, the dialog “expected ‘:’” will be displayed and the offending part of the code will be

¹ Shown messages may depend on the versions of Python and IDLE. Examples given in this chapter uses Python 3.10.12 and IDLE Shell 3.10.12.

shown in red, as shown in the following figure.

The screenshot shows a Python script named 'missing_colon_error.py' in the IDLE editor. A syntax error dialog box titled 'SyntaxError' is displayed, stating 'expected ':''. The line causing the error, 'xx = func1(x)', is highlighted in red. The code contains several comments in Japanese and some English. The error occurs at the end of the line where the closing parenthesis is missing.

```

# エラーを体験する
# 11行目の最後に : がない
def func1(x):
    x = x*x
    return x
# 次の行の最後に : がない
def func2(y, x):
    xx = func1(x)
    return y + xx
# ここからメイン
a = 1
b = 2
print(a, b, func2(a, b))

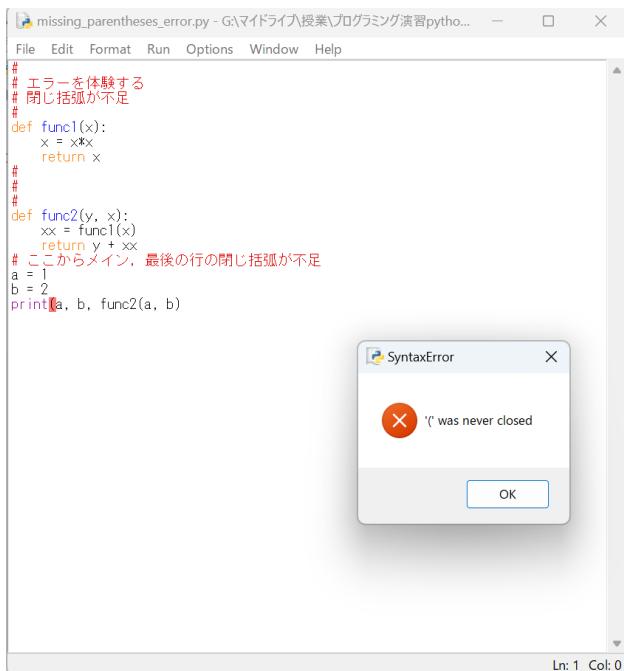
```

19.1.2 Example Program 2 - Missing Parentheses

Program 19-2 missing_parentheses_error.py

Row	Source code	Notes
1	#	
2	#_This_code_will_give_you_some_experience_with_errors	
3	#_Missing_a_closing_parenthesis	
4	#	
5	def func1(x):	
6	x = x*x	
7	return x	
8	#	
9	#_	
10	#	
11	def func2(y, x):	
12	xx = func1(x)	
13	return y + xx	
14	#_The_main_part_starts_here; the_last_line_is_missing_a_cl	
15	osing_parenthesis	
16	a = 1	
17	b = 2	
18	print(a, b, func2(a, b))	Missing a closing parenthesis

In this example, the dialog “‘(was never closed ” is shown, and the corresponding part is displayed in red, as shown in the following figure.



The screenshot shows a Python script named `missing_parentheses_error.py` in the IDLE editor. The code contains several comments in Japanese explaining the purpose of each section. It defines two functions, `func1` and `func2`, and prints their result. A comment indicates that the final line of `func2` lacks a closing parenthesis. When run, a `SyntaxError` dialog box appears, stating `'l' was never closed`. The status bar at the bottom of the IDLE window shows `Ln: 1 Col: 0`.

```

# エラーを体験する
## 閉じ括弧が不足
##
def func1(x):
    x = x*x
    return x

##
def func2(y, x):
    xx = func1(x)
    return y + xx
# ここからメイン、最後の行の閉じ括弧が不足
a = 1
b = 2
print(a, b, func2(a, b))

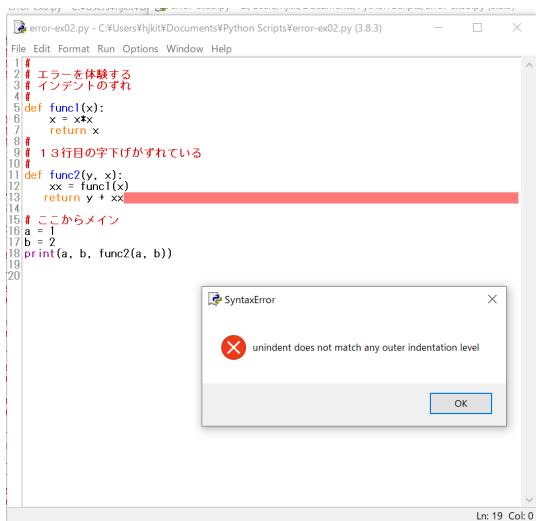
```

19.1.3 Example Program 3 - Indentation Offset (Insufficiency)

Program 19-3 insufficient_indentation_error.py

Row	Source code	Notes
1	#	
2	#_This_code_will_give_you_some_experience_with_errors	
3	#_Indentation_offset	
4	#	
5	def func1(x):	
6	x=x*x	
7	return x	
8	#	
9	#_The_indent_of_line_13_is_offset	
10	#	
11	def func2(y, x):	
12	xx=func1(x)	
13	return y+xx	This indent needs one more space
14		
15	#_Main_from_here	
16	a=1	
17	b=2	
18	print(a, b, func2(a, b))	

In this example, the indentation of line 13 is missing one character, so the message “unindent does not match outer indentation level” is displayed. It warns that the indentation is insufficient, and that there is no matching level.

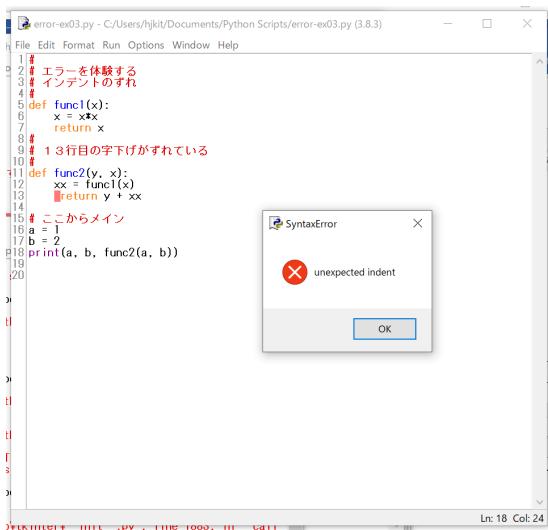


19.1.4 Example Program 4 - Indentation Offset (Excess)

Program 19-4 excess_indentation_error.py

Row	Source code	Notes
1	#	
2	#_This_code_will_give_you_some_experience_with_errors	
3	#_Indentation_offset	
4	#	
5	def func1(x):	
6	x=x*x	
7	return x	
8	#	
9	#_The_indent_of_line_13_is_offset	
10	#	
11	def func2(y, x):	
12	xx=func1(x)	
13	return y+xx	There is an extra space here
14	#_Main_from_here	
15	a=1	
16	b=2	
17	print(a, b, func2(a, b))	

This time the indentation has one character too many, so the error says “unexpected indent.” This can be interpreted to mean that the indentation is unexpected because there is no block that requires further indentation.



19.2 Errors displayed in Python shell when executing code

19.2.1 Example Program 5 - Referencing an Undefined Variable

Program 19-5 referencing_undefined_variable_error.py

Row	Source code	Notes
1	#	
2	#_This_code_will_give_you_some_experience_with_errors	
3	#_Line_6_refers_to_a_variable_that_is_not_defined	
4	#	
5	def func1(x):	
6	xx = xx #_This_variable_does_not_exist	Refers to undefined variable xx
7	return x	
8		
9	def func2(y, x):	
10	xx = func1(x)	
11	return y + xx	
12		
13	#_Main_from_here	
14	a = 1	
15	b = 2	
16	print(a, b, func2(a, b))	

In this example, the Python shell displays the following. Since the error is occurring in the function definition, the traceback will follow the call to the error location. On line 6, it says “**NameError: name 'xx' is not defined. Did you mean: 'x'?**,” indicating that the variable called xx is not defined.

```

Traceback (most recent call last):
  File "M:\Documents\Python Scripts\error-ex1.py", line 16, in <module>
    print(a, b, func2(a, b))
  File "M:\Documents\Python Scripts\error-ex1.py", line 10, in func2
    xx = func1(x)
  File "M:\Documents\Python Scripts\error-ex1.py", line 6, in func1
    x = xx # This variable does not exist
NameError: name 'xx' is not defined. Did you mean: 'x'?
>>>

```

19.2.2 Example Program 6 - Wrong Argument Type

Program 19-6 wrong_argument_type_error.py

Row	Source code	Notes
1	# This code will give you some experience with errors	
2	# When calling math.sin(), the argument is a string	
3	#	
4	import math	
5	def func1(x):	
6	xx=math.sin(x)	
7	return xx	
8		
9	def func2(y,x):	
10	xx=func1(x)	
11	return y+xx	
12		
13	# Main from here	
14	a=1	
15	b="2"	
16	print(a,b,func2(a,b))	set b a string "2" and pass to func2

In this example, the string "2" is passed as an argument to call math.sin(), and the message "TypeError: must be real number, not str" is displayed.

```

Traceback (most recent call last):
  File "M:\Documents\Python Scripts\error-ex2.py", line 17, in <module>
    print(a, b, func2(a, b))
  File "M:\Documents\Python Scripts\error-ex2.py", line 11, in func2
    xx = func1(x)
  File "M:\Documents\Python Scripts\error-ex2.py", line 7, in func1
    xx = math.sin(x)
TypeError: must be real number, not str
>>>

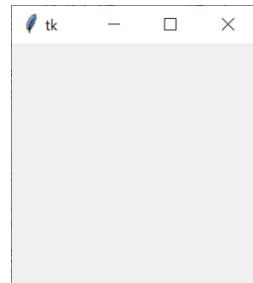
```

19.2.3 Example Program 7 - Incorrect Indentation in a Class

Program 19-7 incorrect_indentation_in_class_error.py

Row	Source code	Notes
1	#	
2	#_This_code_wILL_give_you_sOME_exPERIEnCE_wITH_ERRORS	
3	#_Indentation_wITHIN_a_cLASS	
4	#	
5	import_math	
6	import_tkinter_as_tk	
7	class MyFrame(tk.Frame):	
8	def __init__(self, master=None):	
9	super().__init__(master)	
10	self.b = tk.Button(self, text="Try!", command=self.do)	
	self.b.grid(row=0, column=0)	
11	#	
12	#_The_indent_BELOW_is_oNE_level_Too_Deep	
13	#	
14	def do(self):	
15	self.b.configure(text="Did")	
16		
17		
18	root = tk.Tk()	
19	f = MyFrame(root)	
20	f.pack()	
21	tk.mainloop()	

This example uses a tkinter class definition that extends the Frame class, but the indentation of the “do” method is one level too deep. This is why MyFrame is assumed to have no attribute called do when called as a button callback function. Also, the creation of the button widget b fails, so only the window of tkinter is displayed, as shown on the right.



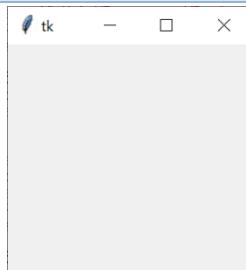
```
Traceback (most recent call last):
  File "M:/Documents/Python Scripts/error-ex3.py", line 20, in <module>
    f = MyFrame(root)
  File "M:/Documents/Python Scripts/error-ex3.py", line 10, in __init__
    self.b = tk.Button(self, text="Try!", command=self.do)
AttributeError: 'MyFrame' object has no attribute 'do'. Did you mean: '_do'?
>>>
```

19.2.4 Example Program 8 - Incorrect Optional Argument

Program 19-8 incorrect_optional_argument_error.py

Row	Source code	Notes
1	#	
2	#_This_code_wILL_give_you_sOME_exPERIEnCE_wITH_ERRORS	
3	#_Incorrect_widget_option	
4	#	
5	import_math	
6	import_tkinter_as_tk	
7	class_MyFrame(tk.Frame):	
8	def __init__(self, master=None):	
9	super().__init__(master)	
10	self.b=tk.Button(self, text="Try!", commend=self.do)	it says "commend"
	self.b.grid(row=0, column=0)	
11	def do(self):	
12	self.b.configure(text="Did")	
13		
14		
15	root=tk.Tk()	
16	f=MyFrame(root)	
17	f.pack()	
18	tk.mainloop()	

This example uses a class definition that extends the Frame class in tkinter, but the optional argument for the button widget in line 10 is spelled incorrectly. The creation of the button widget b will fail, so only the tkinter window will be displayed as shown in the figure on the right. It is difficult to see where the error occurs because it is in the tkinter module, but from the error code ‘unknown option “-commend”’ you can see that the error occurs when calling line 10, and that an option is wrongly specified.



Traceback (most recent call last):

```
File "M:/Documents/Python Scripts/error-ex4.py", line 17, in <module>
    f = MyFrame(root)
File "M:/Documents/Python Scripts/error-ex4.py", line 10, in __init__
    self.b = tk.Button(self, text="Try!", commend=self.do)
File "M:\anaconda3\lib\tkinter\__init__.py", line 2645, in __init__
    Widget.__init__(self, master, 'button', cnf, kw)
File "M:\anaconda3\lib\tkinter\__init__.py", line 2567, in __init__
    self.tk.call(
_tkinter.TclError: unknown option "-commend"
>>>
```

Traceback (most recent call last):

```
File "M:/Documents/Python Scripts/error-ex4.py", line 17, in <module>
    f = MyFrame(root)
File "M:/Documents/Python Scripts/error-ex4.py", line 10, in __init__
```

```

self.b = tk.Button(self, text="Try!", command=self.do)
File "M:\anaconda3\Lib\tkinter\__init__.py", line 2645, in __init__
    Widget.__init__(self, master, 'button', cnf, kw)
File "M:\anaconda3\Lib\tkinter\__init__.py", line 2567, in __init__
    self.tk.call(
_tkinter.TclError: unknown option "-command"
>>>

```

19.2.1 Example Program 9 - Errors within Functions

Program 19-9 error-in-function.py

Row	Source Code
1	# Error that occurs where the function is called
2	def fun1(x):
3	"""Returns the absolute value"
4	return abs(x)
5	def fun2(x,y):
6	"""Returns the absolute value of the sum of the two arguments"
7	z=x+y
8	return fun1(z)
9	# Main program starts here
10	# This works properly
11	a=1
12	b=-5
13	print(a,b,fun2(a,b))
14	# The sum of a string of characters can be calculated, but
15	# one cannot take its absolute value
16	a="X"
17	b="Y"
18	print(a,b,fun2(a,b))

In this example, the function fun2 calls the function that calculates absolute values and then returns the absolute value of the sum of the two arguments. The function fun2 is read in 13th row, but no issue is encountered because both arguments are integers. On the other hand, the two arguments on 18th row are character strings, so while the sum can be calculated, the absolute value written on 4th row cannot.

The results of running this problem can be seen below. The 17th row is run which then leads to 8th row being run. Within that, one can see that the error arises upon trying to run 4th row.

Even when using functions from modules one can easily pinpoint where the function is being called which makes it easier to find errors.

```

1 -5 4
Traceback (most recent call last):
  File "C:/Users/hjkit/Documents/Python Scripts/func-err.py", line 17, in <module>
    print(a, b, fun2(a, b))

```

```
File "C:/Users/hjkit/Documents/Python Scripts/func-err.py", Line 8, in fun2
    return fun1(z)
File "C:/Users/hjkit/Documents/Python Scripts/func-err.py", Line 4, in fun1
    return abs(x)
TypeError: bad operand type for abs(): 'str'
>>>
```