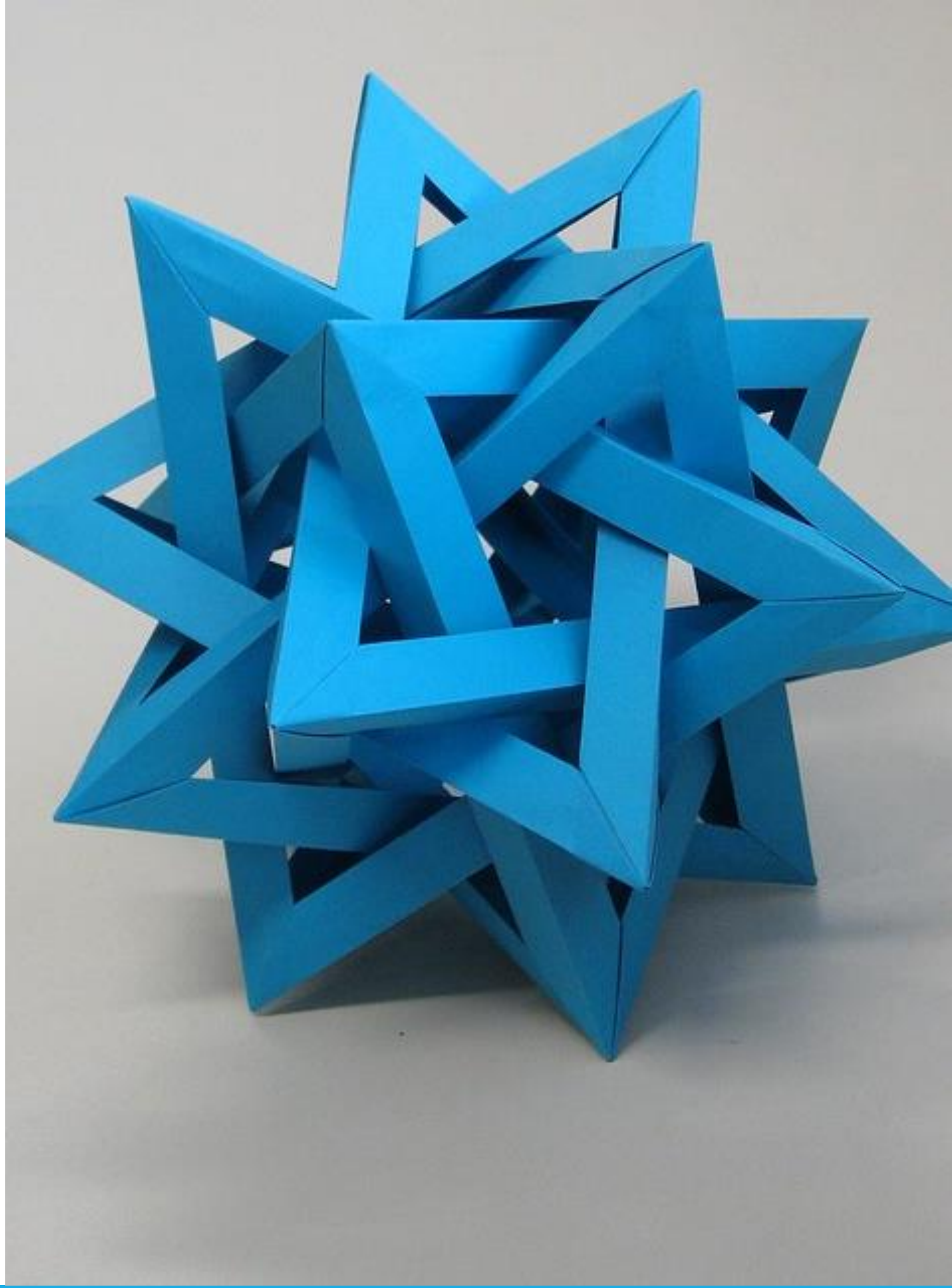
POLITECNICO
DI TORINO

Dipartimento
di Automatica e Informatica

Unit P4: Loops

LOOPS, REPETITIONS, CYCLES, RANGES, SEQUENCES

Chapter 4



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Unit Goals

- To implement while and for loops
- To hand-trace the execution of a program
- To become familiar with common loop algorithms
- To understand nested loops
- To implement programs that read and process data sets
- To use a computer for simulations

- In this unit, you will learn about loop statements in Python, as well as techniques for writing programs that simulate activities in the real world.

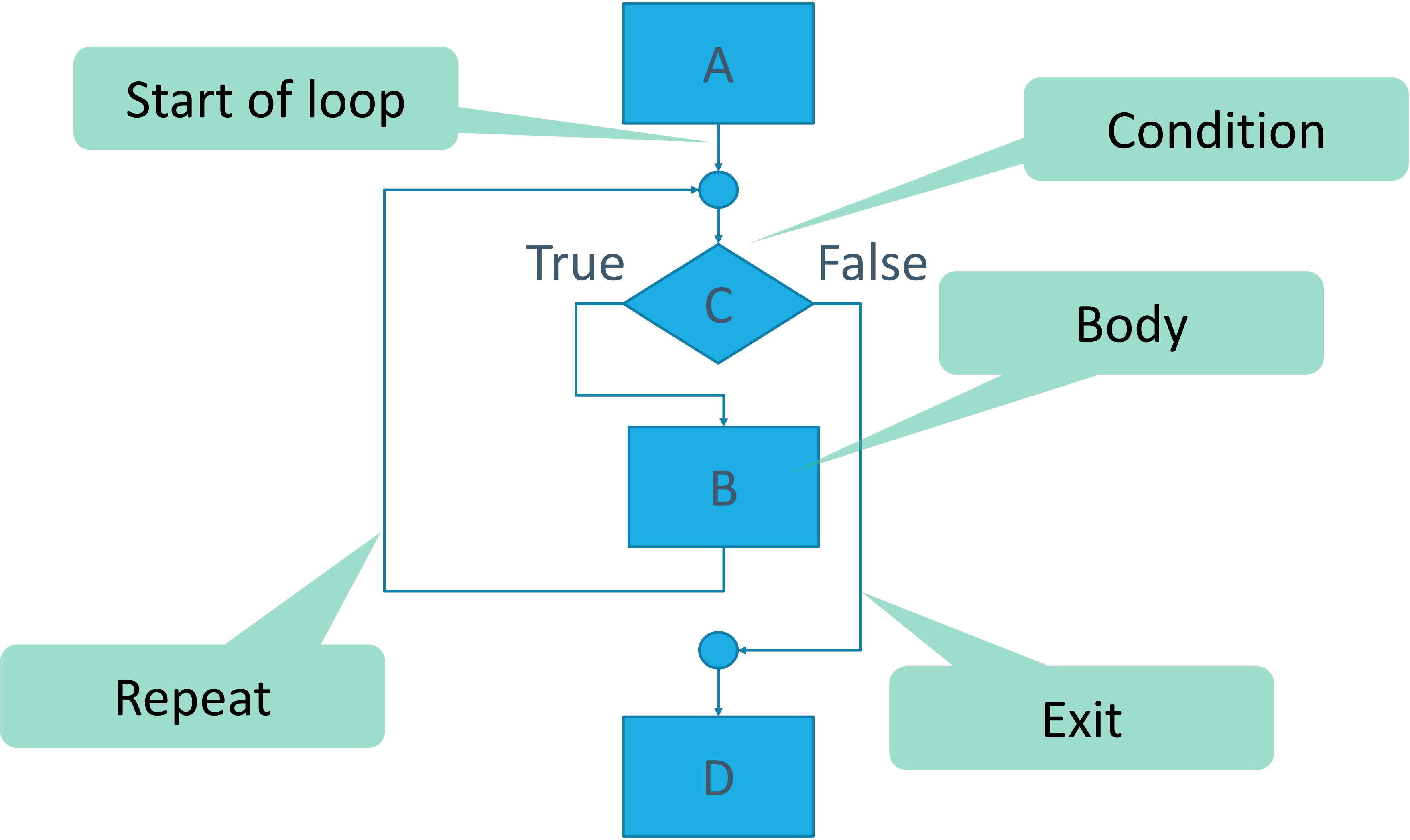
The `while` Loop

4.1

The `while` Loop

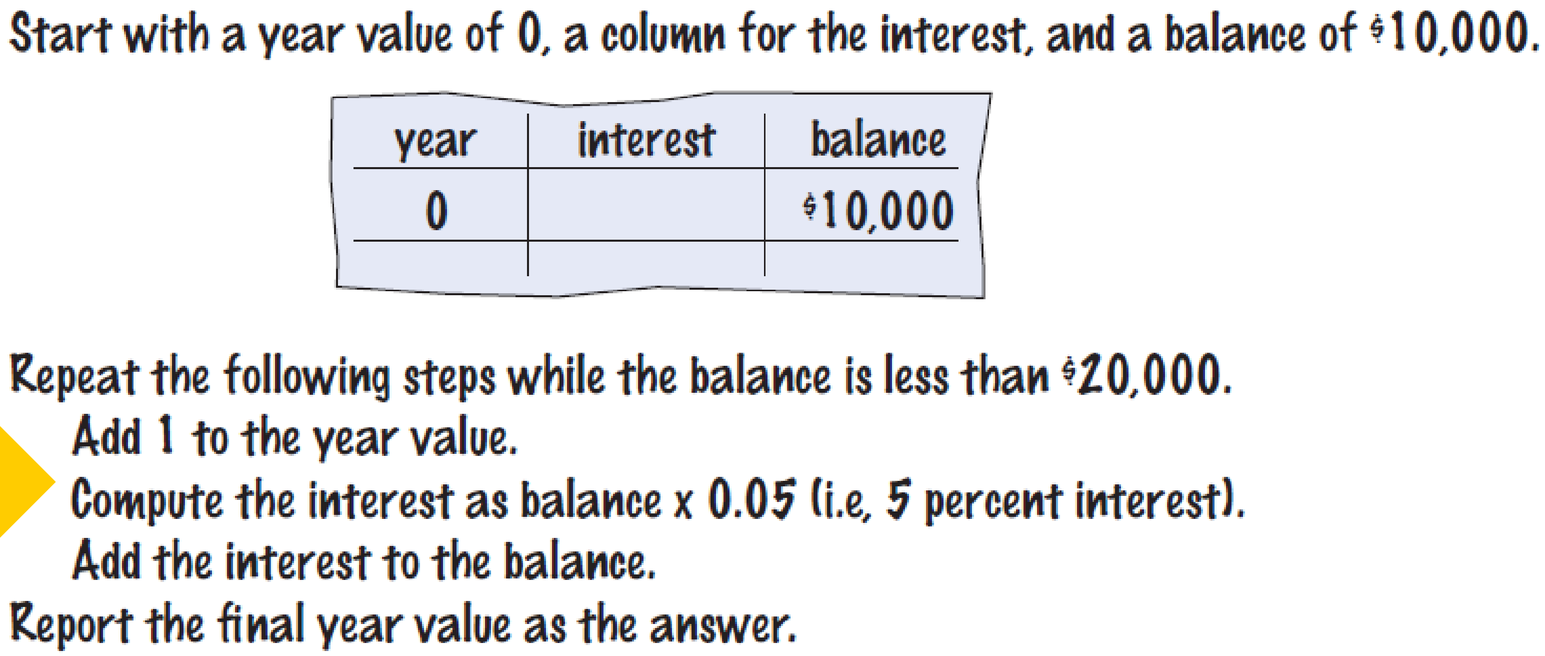
- Loops are used to repeat several times a block of instructions
  - With different values of the variables
  - Until some ‘exit condition’ becomes true
- Examples of loop applications
  - Calculating compound interest
  - Simulations, event driven programs
  - Drawing tiles…

While loop - flowchart



Example

- Compound interest algorithm (Chapter 1)



Start with a year value of 0, a column for the interest, and a balance of $10,000.

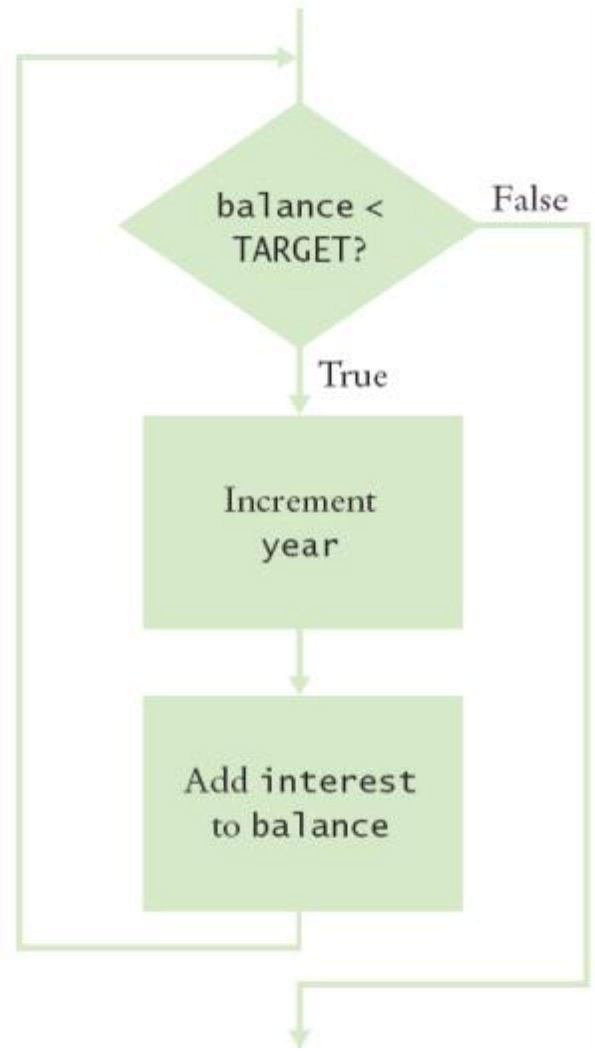
year	interest	balance
0		$10,000

```
Repeat the following steps while the balance is less than $20,000.
    Add 1 to the year value.
    Compute the interest as balance x 0.05 (i.e, 5 percent interest).
    Add the interest to the balance.
Report the final year value as the answer.
```

Steps

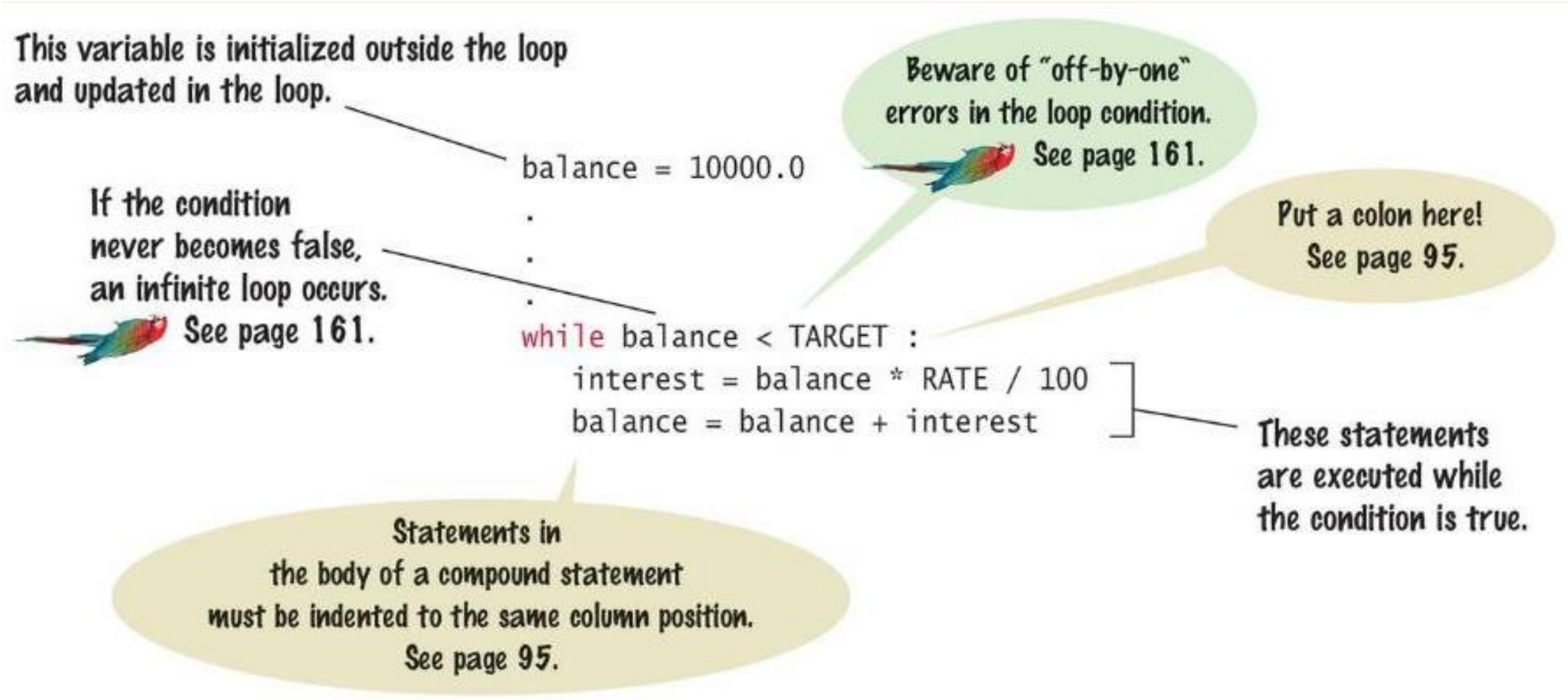
Planning the while Loop

```
balance = 10.0
target = 100.0
year = 0
RATE = 0.025
while balance < TARGET :
   year = year + 1
   interest = balance * RATE/100
   balance = balance + interest
```



- A loop executes instructions repeatedly while its condition is True.

Syntax: `while` Statement



```
balance = 10000.0
.
.
.
while balance < TARGET :
   interest = balance * RATE / 100
   balance = balance + interest
```

This variable is initialized outside the loop and updated in the loop.

If the condition never becomes false, an infinite loop occurs. See page 161.

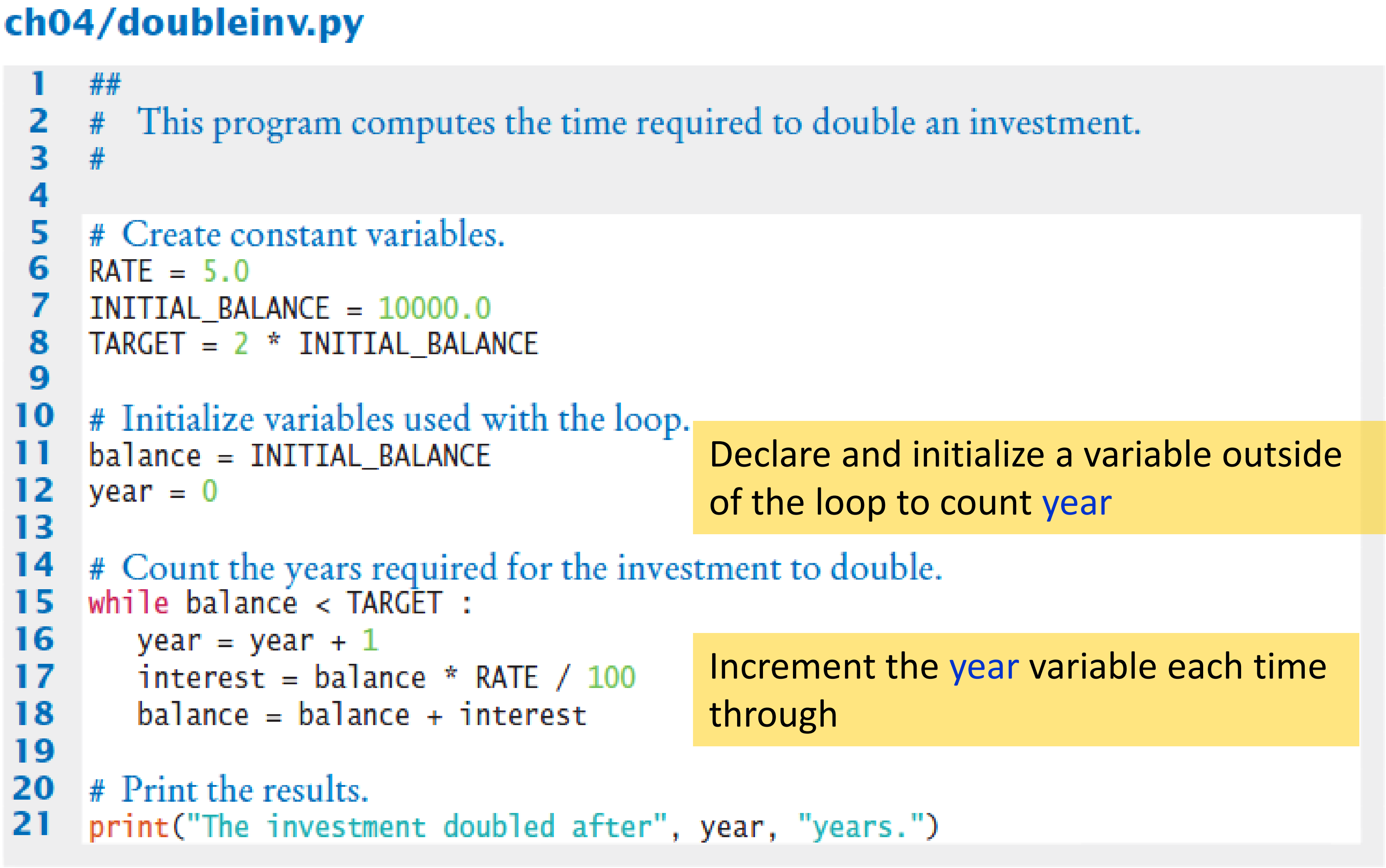
Beware of "off-by-one" errors in the loop condition. See page 161.

Put a colon here! See page 95.

These statements are executed while the condition is true.

Statements in the body of a compound statement must be indented to the same column position. See page 95.

Doubleinv.py



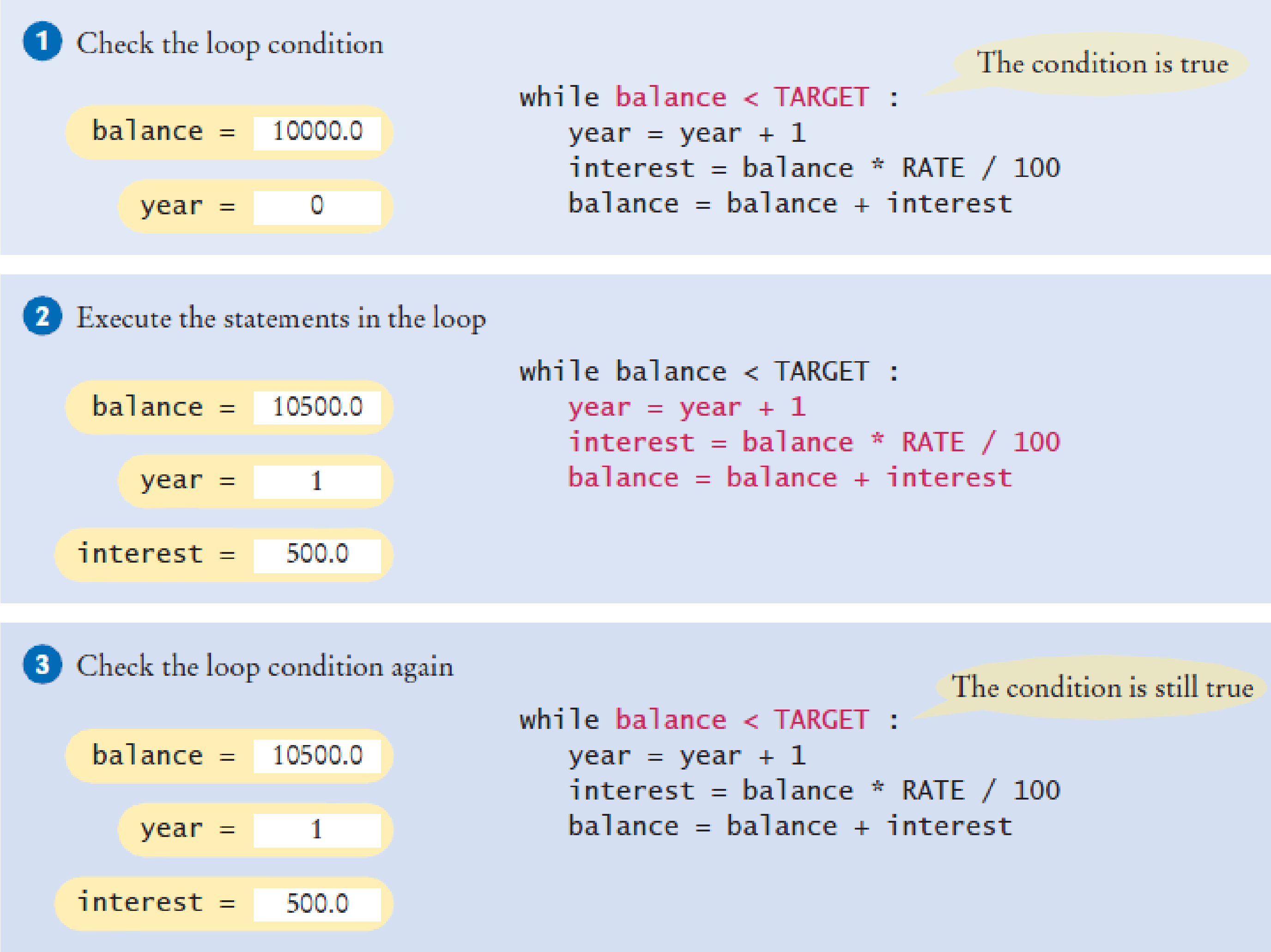
ch04/doubleinv.py

```python
##
#   This program computes the time required to double an investment.
#

# Create constant variables.
RATE = 5.0
INITIAL_BALANCE = 10000.0
TARGET = 2 * INITIAL_BALANCE

# Initialize variables used with the loop.
balance = INITIAL_BALANCE
year = 0

# Count the years required for the investment to double.
while balance < TARGET :
   year = year + 1
   interest = balance * RATE / 100
   balance = balance + interest

# Print the results.
print("The investment doubled after", year, "years.")
```

Declare and initialize a variable outside of the loop to count year

Increment the year variable each time through

Execution of the Loop



1 Check the loop condition

```
balance =  10000.0
   year =  0
```

```
while balance < TARGET :
   year = year + 1
   interest = balance * RATE / 100
   balance = balance + interest
```

The condition is true

2 Execute the statements in the loop

```
 balance =  10500.0
    year =  1
interest =  500.0
```

```
while balance < TARGET :
   year = year + 1
   interest = balance * RATE / 100
   balance = balance + interest
```

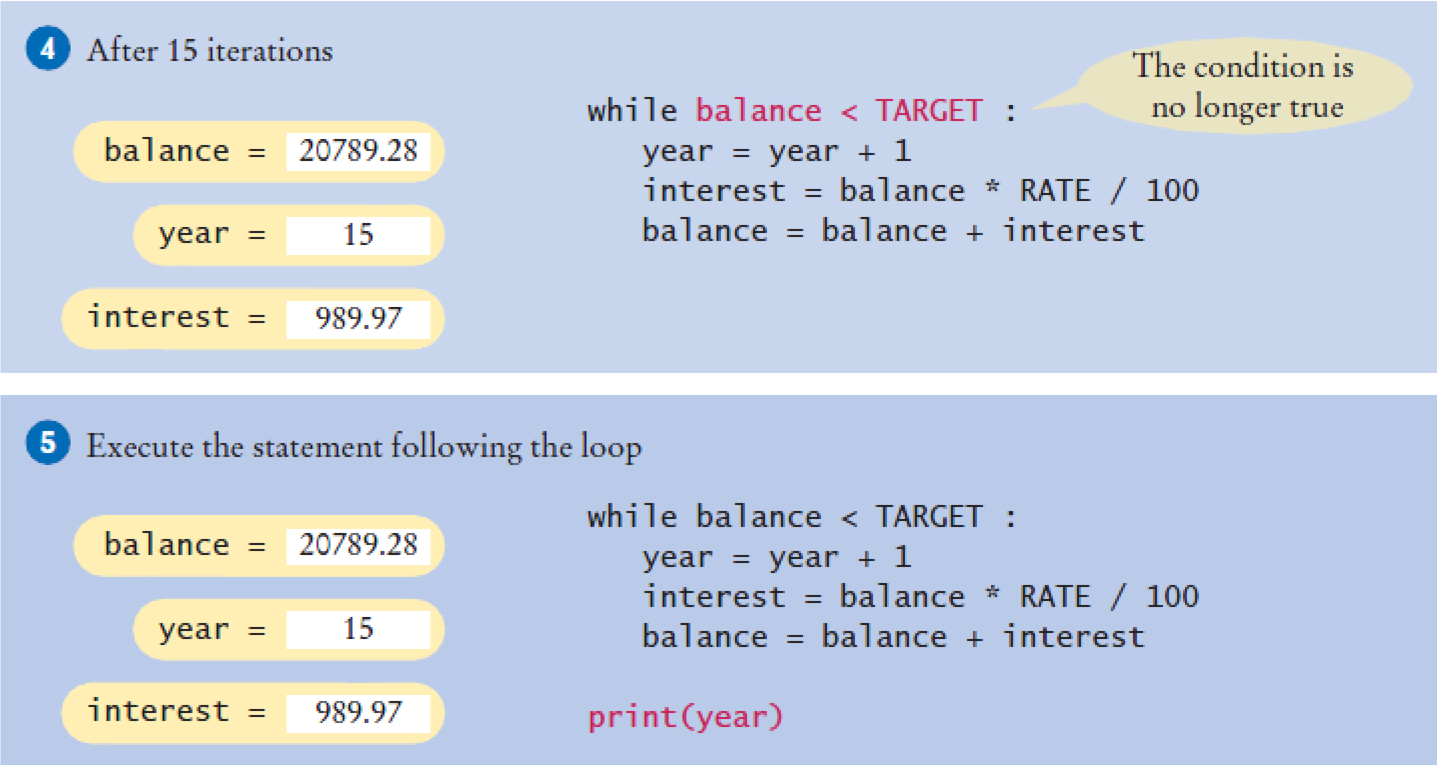
3 Check the loop condition again

```
 balance =  10500.0
    year =  1
interest =  500.0
```

```
while balance < TARGET :
   year = year + 1
   interest = balance * RATE / 100
   balance = balance + interest
```

The condition is still true

Execution of the Loop (2)



4 After 15 iterations

balance = 20789.28

year = 15

interest = 989.97

```
while balance < TARGET :
    year = year + 1
    interest = balance * RATE / 100
    balance = balance + interest
```

The condition is no longer true

5 Execute the statement following the loop

balance = 20789.28

year = 15

interest = 989.97

```
while balance < TARGET :
    year = year + 1
    interest = balance * RATE / 100
    balance = balance + interest

print(year)
```

Count-Controlled Loops

- A `while` loop that is controlled by a **counter**
  - Counts the number of iterations already done
  - Stops when a predefined number of iterations has been completed

```
counter = 1             # Initialize the counter
while counter <= 10 :   # Check the counter
    print(counter)
    counter = counter + 1    # Update the loop variable
```

Event-Controlled Loops

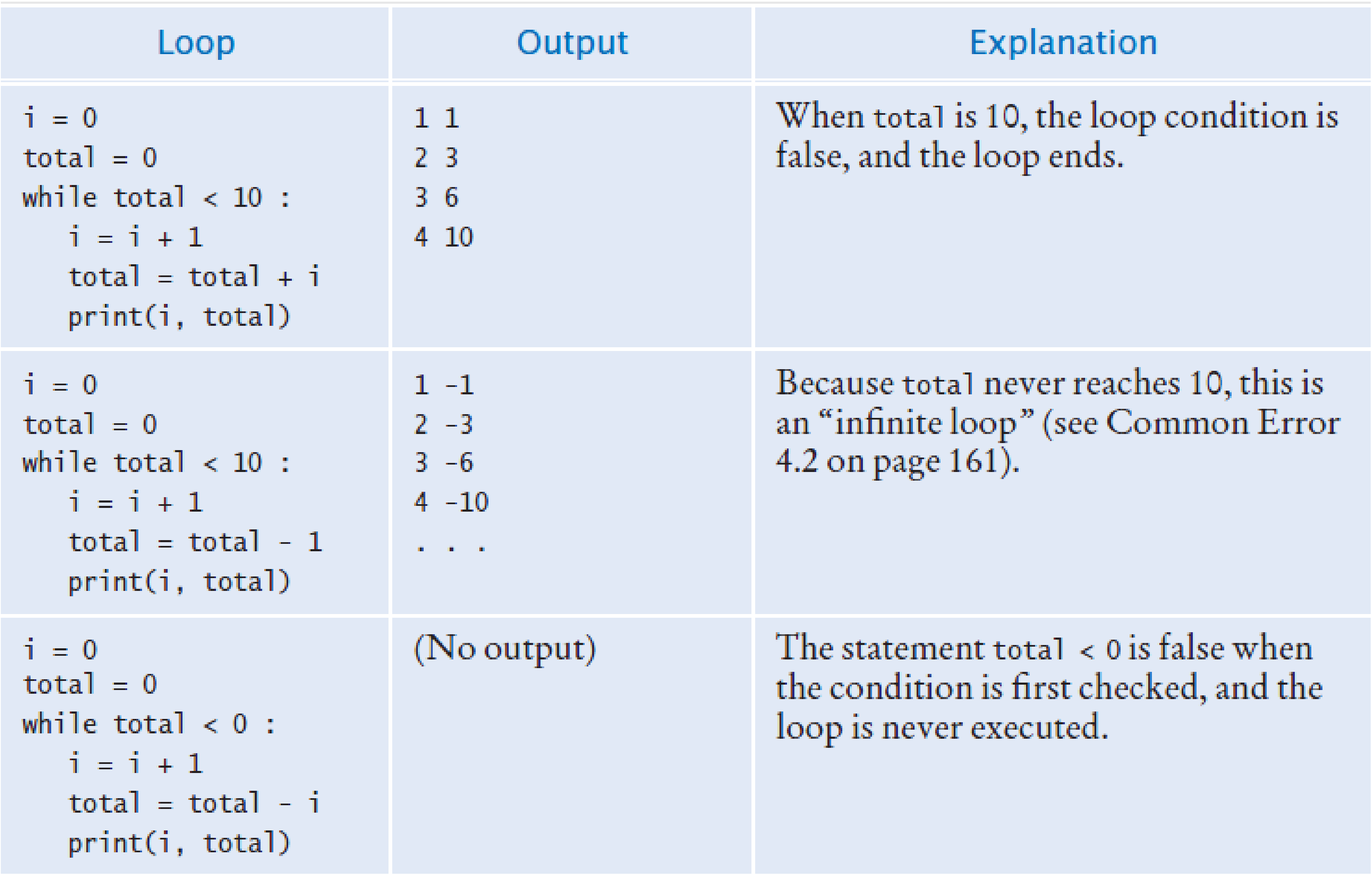
- A `while` loop that is controlled by a condition that, sooner or later, will become True
  - The number of iterations is not known in advance

```
balance = INITIAL_BALANCE  # Initialize the loop variable
while balance <= TARGET:   # Check the loop variable
    year = year + 1
    balance = balance * 2  # Update the loop variable
```

Investment Example

- Open the file:
  - Doubleinv.py
- Run the program with several test cases
  - The program will prompt you for a rate
  - Enter a mix of valid and invalid rates

while Loop Examples



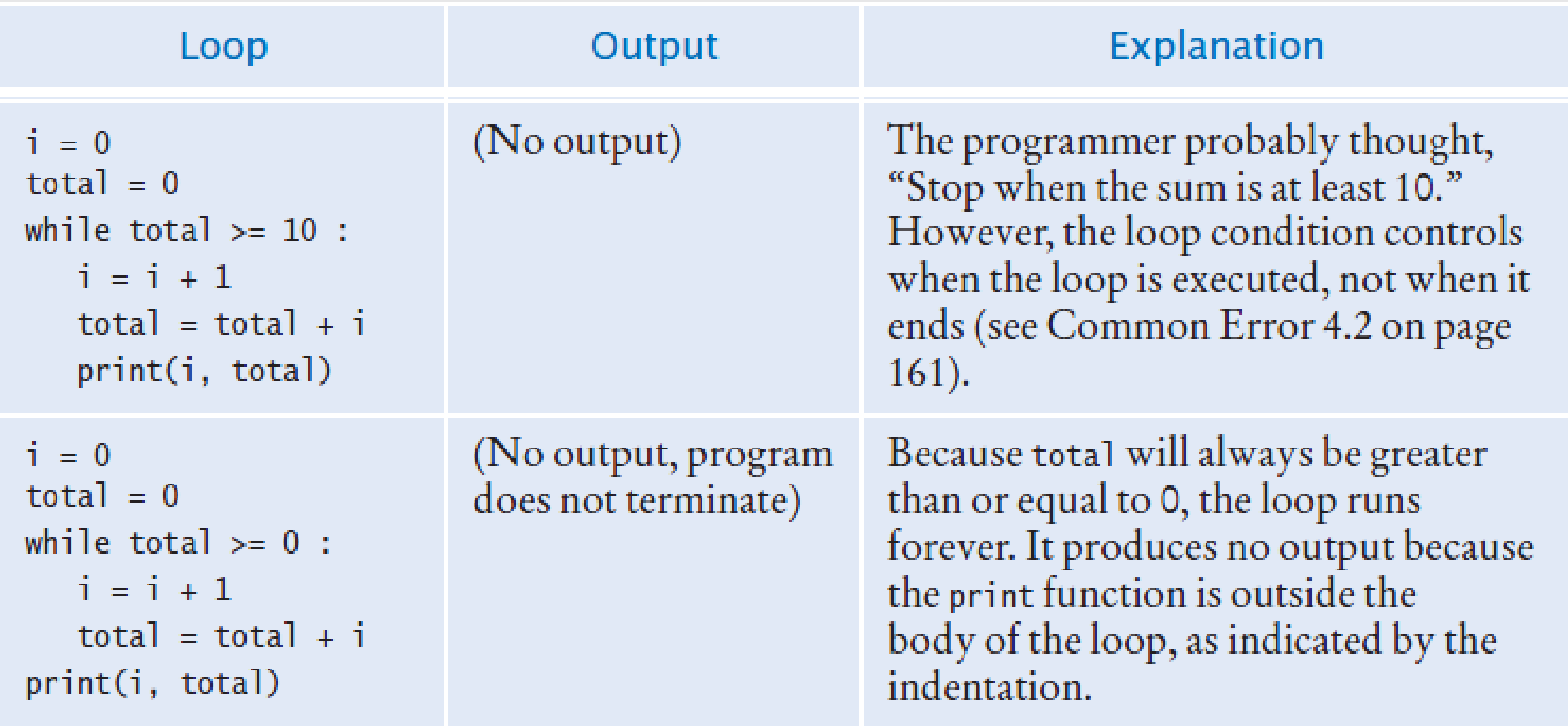
Loop	Output	Explanation

i = 0
total = 0
while total < 10 :
    i = i + 1
    total = total + i
    print(i, total)
	1 1
	2 3
	3 6
	4 10
		When total is 10, the loop condition is false, and the loop ends.

i = 0
total = 0
while total < 10 :
    i = i + 1
    total = total - 1
    print(i, total)
	1 -1
	2 -3
	3 -6
	4 -10
	. . .
		Because total never reaches 10, this is an "infinite loop" (see Common Error 4.2 on page 161).

i = 0
total = 0
while total < 0 :
    i = i + 1
    total = total - i
    print(i, total)
	(No output)	The statement total < 0 is false when the condition is first checked, and the loop is never executed.

`while` Loop Examples (2)



Loop	Output	Explanation

`i = 0`
`total = 0`
`while total >= 10 :`
`    i = i + 1`
`    total = total + i`
`    print(i, total)`
	(No output)	The programmer probably thought, "Stop when the sum is at least 10." However, the loop condition controls when the loop is executed, not when it ends (see Common Error 4.2 on page 161).

`i = 0`
`total = 0`
`while total >= 0 :`
`    i = i + 1`
`    total = total + i`
`print(i, total)`
	(No output, program does not terminate)	Because `total` will always be greater than or equal to `0`, the loop runs forever. It produces no output because the `print` function is outside the body of the loop, as indicated by the indentation.

Common Error: **Incorrect Test Condition**

- The loop body will only execute if the test condition is `True`.
- We assume bal is initialized as less than the TARGET and should grow until it reaches TARGET
  - Which version will execute the loop body?

```
while bal >= TARGET :
    year = year + 1
    interest = bal * RATE
    bal = bal + interest
```

```
while bal < TARGET :
    year = year + 1
    interest = bal * RATE
    bal = bal + interest
```

Common Error: **Infinite Loops**

- The loop body will execute until the test condition becomes `False`.
- What if you forget to update the test variable?
  - bal is the test variable (TARGET doesn’t change)
  - You will loop forever! (or until you stop the program)

```
while bal < TARGET :
   year = year + 1
   interest = bal * RATE
   bal = bal + interest
```

Common Error: **Off-by-One Errors**

- A ‘counter’ variable is often used in the test condition
- Your counter can start at 0 or 1, but programmers often start a counter at 0
- If I want to paint all 5 fingers on one hand, when am I done?
    - If you start at 0, use “<“
    - 0, 1, 2, 3, 4

If you start at 1, use “<=“

1, 2, 3, 4, 5

```
finger = 0
FINGERS = 5
while finger < FINGERS :
   # paint finger
   finger = finger + 1
```

```
finger = 1
FINGERS = 5
while finger <= FINGERS :
   # paint finger
   finger = finger + 1
```

Mixed loops

- Not every loop is count-controlled or event-controlled
- Example: read a sequence of 10 numbers, but stop if you read 0

```
count = 0
ok = True

while (count < 10) and ok :
  a = int(input('Number: '))
  if a==0:
    ok = False
  print(f'Number {count+1}={a}')
  count = count + 1
```

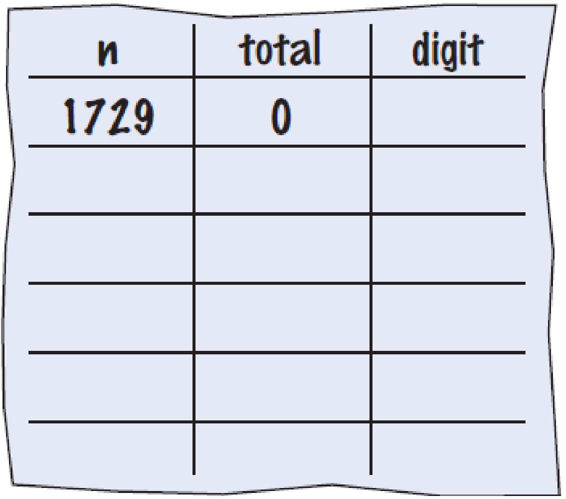
Hand Tracing Loops 📘 4.2

Hand-Tracing Loops

- Example: Calculate the sum of digits (1+7+2+9)
  - Make columns for key variables (n, total, digit)
  - Examine the code and number the steps
  - Set variables to state before loop begins

```
n = 1729
total = 0
while n > 0 :
   digit = n % 10
   total = total + digit
   n = n // 10

print(total)
```

Trace loop behavior



n	total	digit
1729	0	

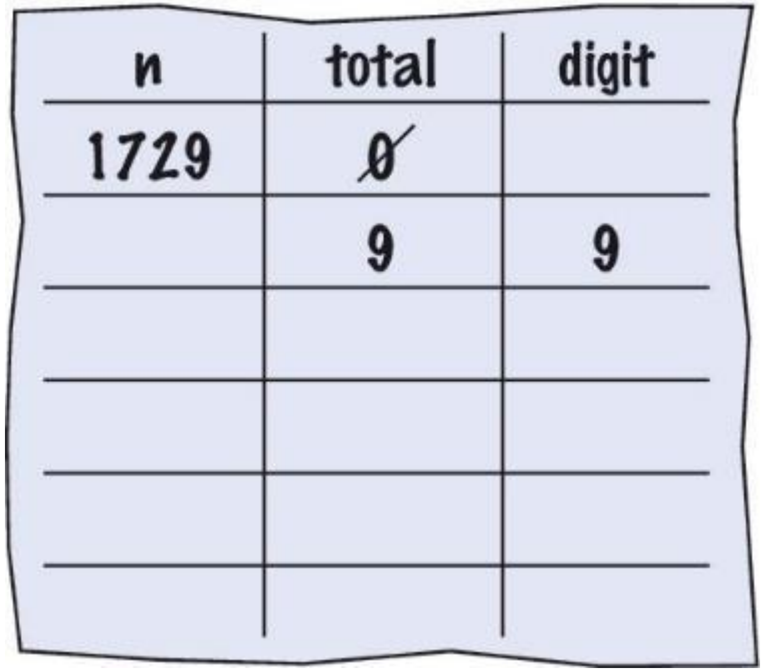
Tracing Sum of Digits

n	total	digit
1729	0	

```
n = 1729
total = 0
while n > 0 :
    digit = n % 10
    total = total + digit
    n = n // 10

print(total)
```

- Start executing loop body statements changing variable values on a new line
  - Cross out values in previous lines

Tracing Sum of Digits



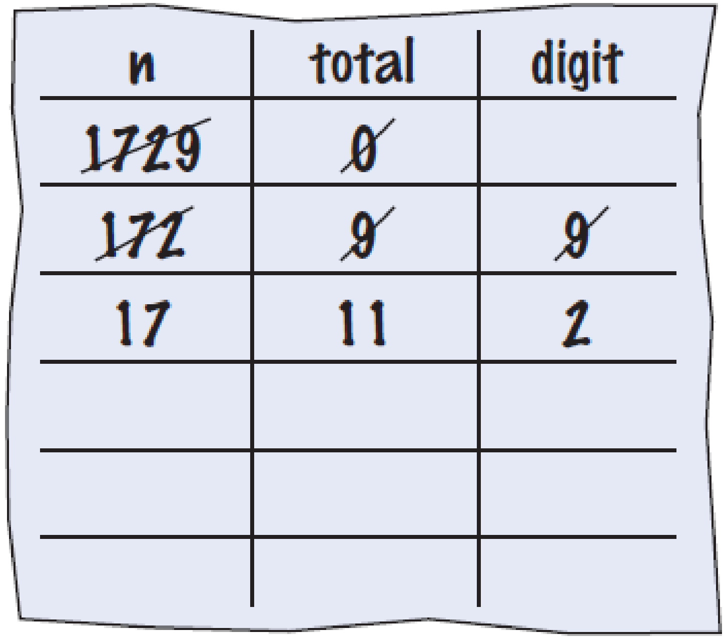
n	total	digit
1729	~~0~~	
	9	9

```
n = 1729
total = 0
while n > 0 :
   digit = n % 10
   total = total + digit
   n = n // 10

print(total)
```

- Continue executing loop statements changing variables
  - 1729 / 10 leaves 172 (no remainder)

Tracing Sum of Digits

- Test condition. If True, execute loop again
  - Variable n is 172, Is 172 > 0?, True!
- Make a new line for the second time through and update variables

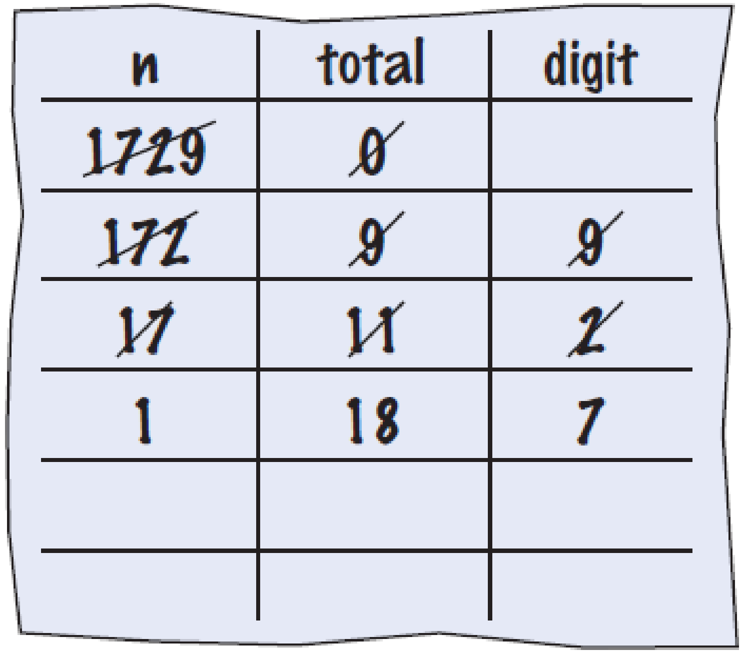


n	total	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
17	11	2

```
n = 1729
total = 0
while n > 0 :
    digit = n % 10
    total = total + digit
    n = n // 10

print(total)
```

Tracing Sum of Digits

- Third time through
  - Variable n is 17 which is still greater than 0
- Execute loop statements and update variables

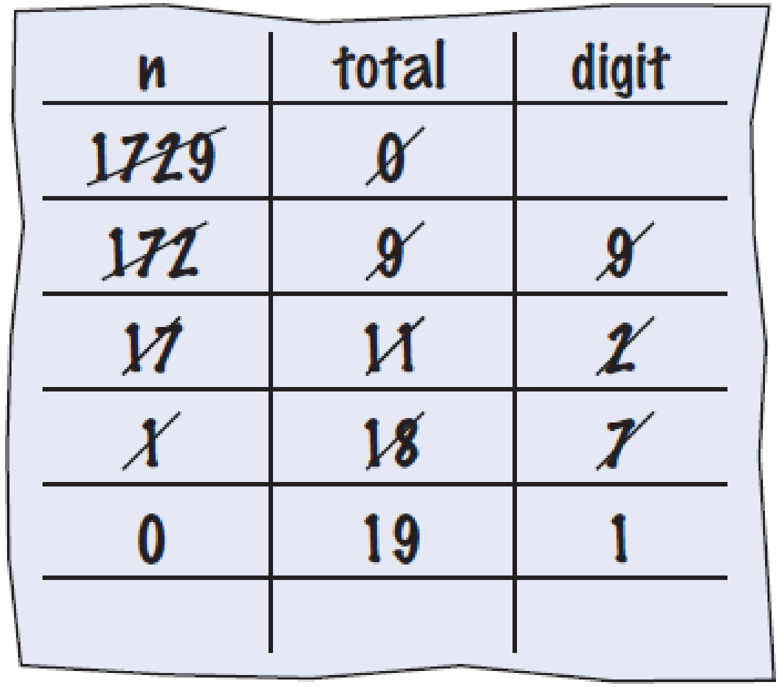


n	total	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
~~17~~	~~11~~	~~2~~
1	18	7

```
n = 1729
total = 0
while n > 0 :
    digit = n % 10
    total = total + digit
    n = n // 10

print(total)
```

Tracing Sum of Digits

- Fourth loop iteration:
  - Variable n is 1 at start of loop. 1 > 0? True
  - Executes loop and changes variable n to 0 (1/10 = 0)

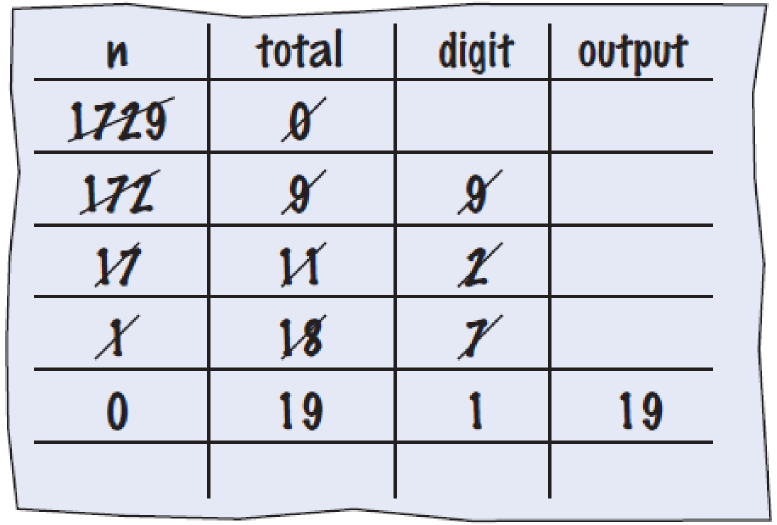


n	total	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
~~17~~	~~11~~	~~2~~
~~1~~	~~18~~	~~7~~
0	19	1

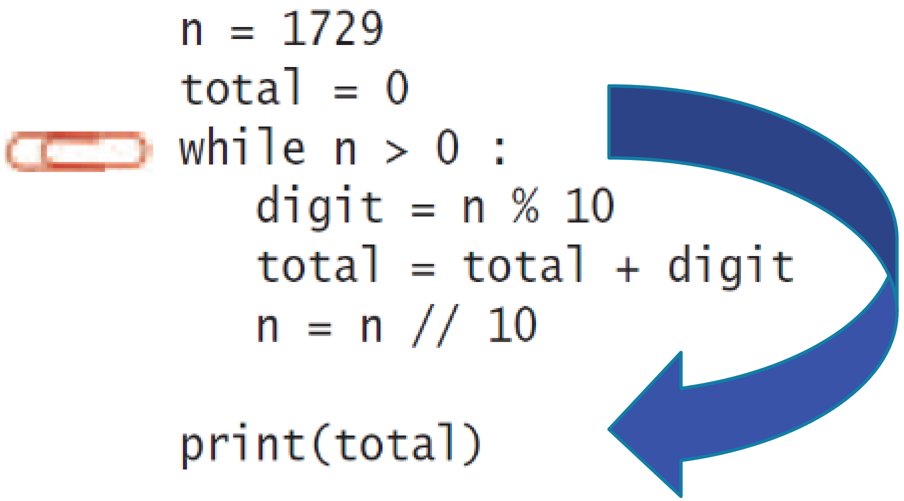
```
n = 1729
total = 0
while n > 0 :
    digit = n % 10
    total = total + digit
    n = n // 10

print(total)
```

Tracing Sum of Digits

- Because n is 0, the expression(n > 0) is False
- Loop body is not executed
  - Jumps to next statement after the loop body
- Finally prints the sum!



n	total	digit	output
~~1729~~	~~0~~		
~~172~~	~~9~~	~~9~~	
~~17~~	~~11~~	~~2~~	
~~1~~	~~18~~	~~7~~	
0	19	1	19



```
n = 1729
total = 0
while n > 0 :
    digit = n % 10
    total = total + digit
    n = n // 10

print(total)
```

Summary of the `while` Loop

- `while` loops are very common
- Initialize variables before you perform the test
  - The condition is tested BEFORE the loop body
    - This is called pre-test
    - The condition often uses a counter variable
- Watch out for infinite loops!
  - Something inside the loop must change one of the variables used in the test
  - The change should (sooner or later) make the test condition `False`

Sentinel Values

📘 4.3

Processing Sentinel Values

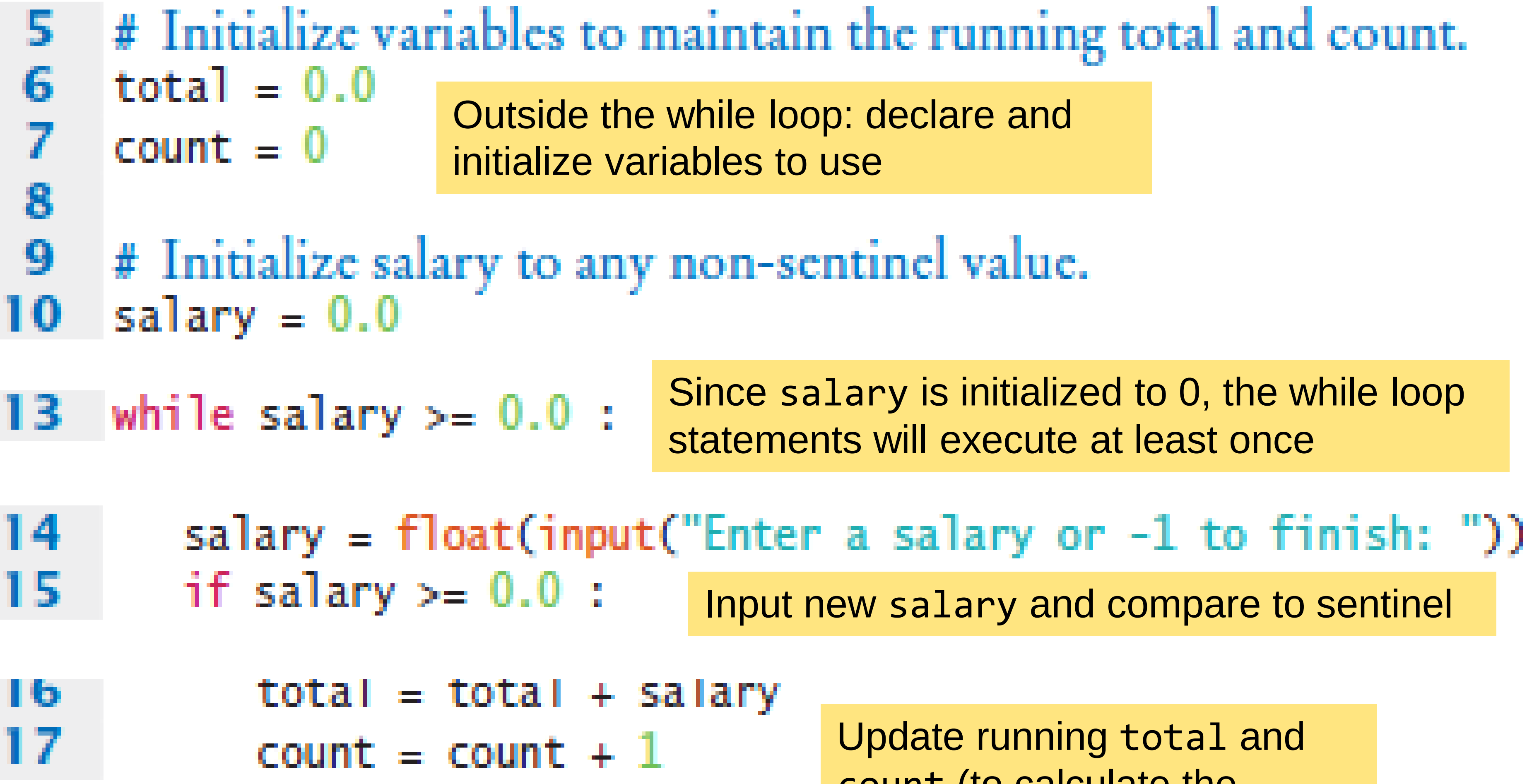
- Whenever you read a sequence of inputs, you need to have some method of indicating the end of the sequence
- When you don’t know how many items are in a list, use a ‘special’ character or value to signal the “last” item
  - This special value is called “sentinel”
  - For numeric input of positive numbers, it is common to use the value -1 or 0
    - A sentinel value denotes the end of a data set, but it is **not** part of the data.

```
salary = 0.0
while salary >= 0 :
   salary = float(input())
      if salary >= 0.0 :
         total = total + salary
         count = count + 1
```

Algorithm: Averaging a Set of Values

- Declare and initialize a ‘total’ variable to 0
- Declare and initialize a ‘count’ variable to 0
- Declare and initialize a ‘salary’ variable to 0
- Prompt user with instructions
- Loop until sentinel value is entered
  - Save entered value to input variable (‘salary’)
  - If salary is not -1 or less (sentinel value)
    - Add salary variable to total variable
    - Add 1 to count variable
- Make sure you have at least one entry before you divide!
  - Divide total by count and output.
  - Done!

Sentinel.py (1)



```
# Initialize variables to maintain the running total and count.
total = 0.0
count = 0
```

Outside the while loop: declare and initialize variables to use

```

# Initialize salary to any non-sentinel value.
salary = 0.0
```

```
while salary >= 0.0 :
```

Since `salary` is initialized to 0, the while loop statements will execute at least once

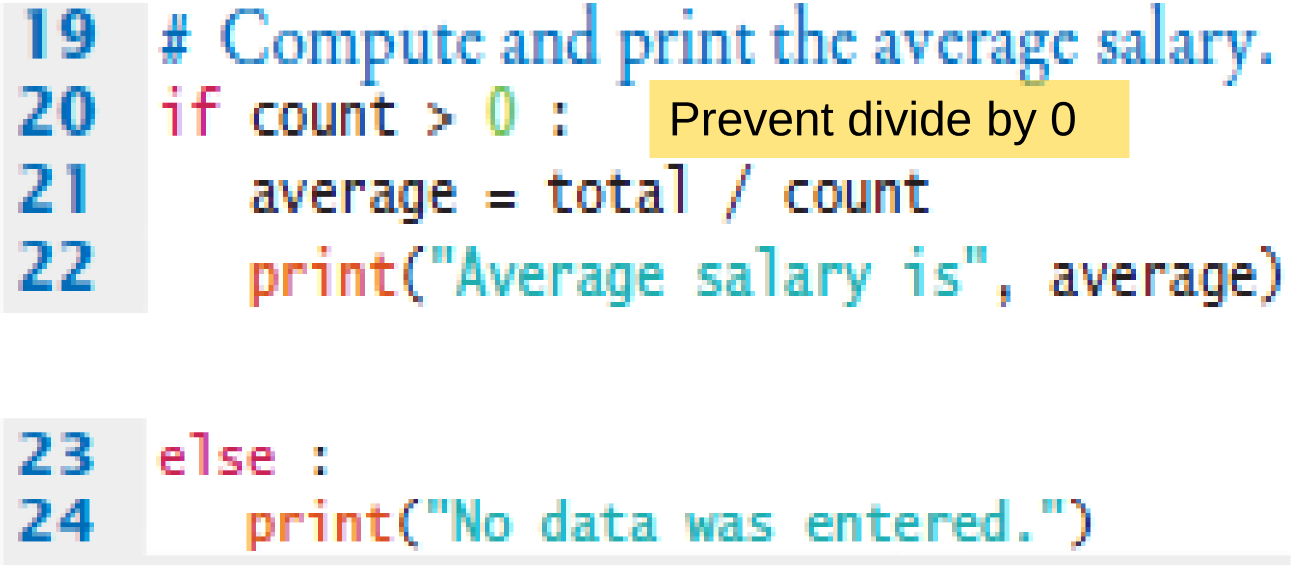
```
    salary = float(input("Enter a salary or -1 to finish: "))
    if salary >= 0.0 :
```

Input new `salary` and compare to sentinel

```
        total = total + salary
        count = count + 1
```

Update running `total` and `count` (to calculate the average later)

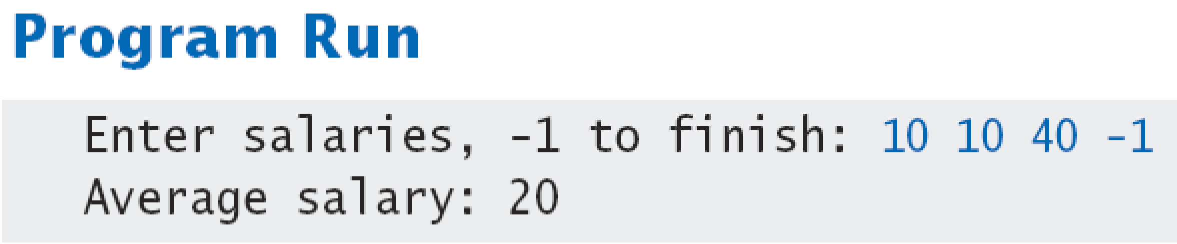
Sentinel.py (2)



```python
# Compute and print the average salary.
if count > 0 :
    average = total / count
    print("Average salary is", average)
else :
    print("No data was entered.")
```

Prevent divide by 0

Calculate and output the average salary using the `total` and `count` variables



Program Run

```
Enter salaries, -1 to finish: 10 10 40 -1
Average salary: 20
```

Sentinel Example

- Open the file:
  - Sentinel.py
- Notice the use of the `if` test inside the while loop
  - The `if` checks to make sure we are not processing the sentinel value

Priming Read

- Some programmers don’t like the “trick” of initializing the input variable with a value other than a sentinel
    - Increases confusion between “legitimate” values and “fake” sentinel values

```
# Set salary to a value to ensure that the loop
# executes at least once.
salary = 0.0
while salary >= 0 :
```

- An alternative is to pre-load the variable with a read before the loop (‘priming’ the variable)

```
salary = float(input("Enter a salary or -1 to finish: "))
while salary >= 0 :
```

Modification Read

- The input operation at the bottom of the loop is used to obtain the next input.

```
# Priming read
salary = float(input("Enter a salary or -1 to finish: "))
while salary >= 0.0 :
   total = total + salary
   count = count + 1
   # Modification read
   salary = float(input("Enter a salary or -1 to finish: "))
```

Boolean Variables and Sentinels

- A boolean variable can be used to control a loop
  - Sometimes called a ‘flag’ variable

```
done = False
while not done :
   value = float(input("Enter a salary or -1 to finish: "))
   if value < 0.0:
      done = True
   else :
      # Process value
```

Initialize done so that the loop will execute

Set done ‘flag’ to True if sentinel value is found

Common Loop Algorithms

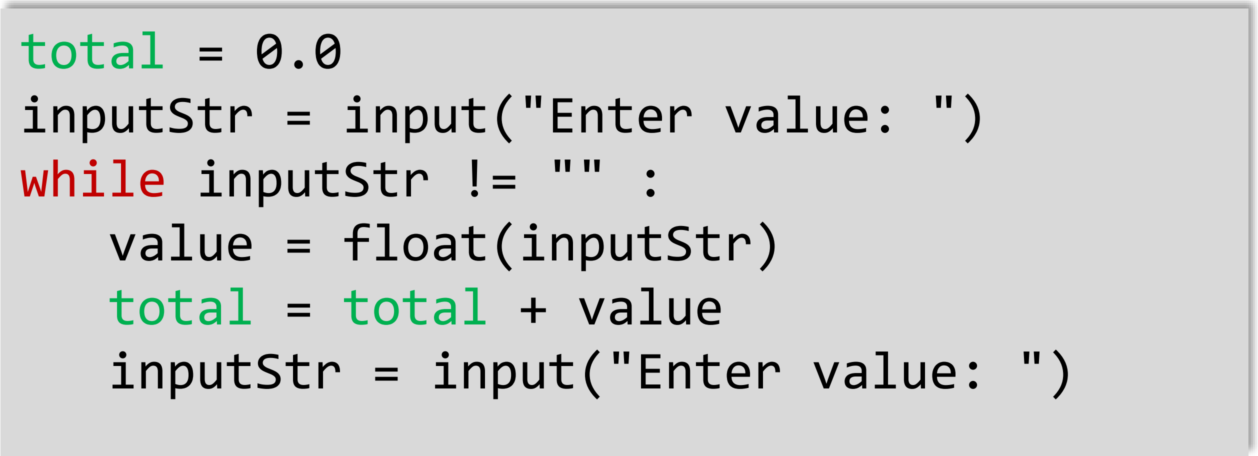
📘 4.5

Common Loop Algorithms

- Sum and Average Value
- Counting Matches
- Prompting until a Match Is Found
- Maximum and Minimum
- Comparing Adjacent Values

Sum of Values

- Initialize total to 0
- Use while loop with sentinel



```
total = 0.0
inputStr = input("Enter value: ")
while inputStr != "" :
   value = float(inputStr)
   total = total + value
   inputStr = input("Enter value: ")
```

Average of ‘count’ values

- First compute total sum of the values
- Initialize count to 0
  - Increment per each input
  - Counting how many values
- Check for count > 0
  - Before divide!

```
total = 0.0
count = 0
inputStr = input("Enter value: ")
while inputStr != "" :
   value = float(inputStr)
   total = total + value
   count = count + 1
   inputStr = input("Enter value: ")

if count > 0 :
   average = total / count
else :
   average = 0.0
```

Counting Matches *(e.g., Negative Numbers)*

- Counting Matches
  - Initialize negatives to 0
  - Use a while loop
  - Add to negatives if the condition matches

```
negatives = 0
inputStr = input("Enter value: ")
while inputStr != "" :
   value = int(inputStr)
   if value < 0 :
      negatives = negatives + 1
   inputStr = input("Enter value: ")

print("There were", negatives,
"negative values.")
```

Prompt Until a Match is Found

- Initialize boolean flag to False
- Test sentinel in while loop
  - Get input, and compare to range
    - If input is in range, change flag to True
    - Loop will stop executing

```
valid = False
while not valid :
   value = int(input("Please enter a positive value < 100: "))
   if value > 0 and value < 100 :
      valid = True
   else :
      print("Invalid input.")
```

This is an excellent way to validate provided inputs

Maximum

- Get first input value
  - By definition, this is the largest that you have seen so far
- Loop while you have a valid number (non-sentinel)
  - Get another input value
  - Compare new input to largest
  - Update largest if necessary

```
largest = int(input("Enter a value: "))
inputStr = input("Enter a value: ")
while inputStr != "" :
   value = int(inputStr)
   if value > largest :
      largest = value
   inputStr = input("Enter a value: ")
```

Minimum

- Get first input value
  - This is the smallest that you have seen so far!
- Loop while you have a valid number (non-sentinel)
  - Get another input value
  - Compare new input to largest
  - Update smallest if necessary

```
smallest = int(input("Enter a value: "))
inputStr = input("Enter a value: ")
while inputStr != "" :
   value = int(inputStr)
   if value < smallest :
      smallest = value
   inputStr = input("Enter a value: ")
```

Comparing Adjacent Values

- Get first input value
- Use while to determine if there are more to check
  - Copy `value` to `previous` variable
  - Get next value into `value` variable
  - Compare `value` to `previous`, and print if same

```
value = int(input("Enter a value: ")) # 1st
inputStr = input("Enter a value: ")
while inputStr != "" :
   previous = value
   value = int(inputStr)
   if value == previous :
      print("Duplicate input")
   inputStr = input("Enter a value: ")
```

Grades Example

- Open the file:
  - Grades.py
- Look carefully at the source code.
- The maximum possible score is read as user input
  - There is a loop to validate the input
- The passing grade is computed as 60% of the available points

The for Loop

📘 4.6

The `for…in` Loop

- Uses of a `for…in` loop:
  - The for loop can be used to iterate over the contents of any container
- A container is an object (like a string) that contains or stores a collection of elements
- Python has several types of containers
  - A string is a container that stores the collection of characters in the string
  - A list (Chapter 6) is a container of arbitrary values
  - A file (Chapter 7) is a container or rows of text

An Example of a for Loop

```
stateName = "Virginia"
i = 0
while i < len(stateName) :
   letter = stateName[i]
   print(letter)
   i = i + 1
```

while version

```
stateName = "Virginia"
for letter in stateName :
   print(letter)
```

for version

- Note an important difference between the while loop and the for loop.
- In the while loop, the index variable i is assigned 0, 1, and so on.
- In the for loop, the element variable is assigned the sequence elements:
  - stateName[0], stateName[1], and so on.
- Note: “Virginia” is a container of the sequence “V”, “i”, “r”, “g”, “i”, “n”, “i”, “a”

The ‘`range`’ container

- A special container is a sequence of consecutive numbers
- Generated with the `range(N)` function
  - `range(N)` creates a sequence of integers from `0` to `N-1`
- Therefore a `for` loop with a `range()` will execute as a counter-based `while` loop

The for Loop (2)

- Uses of a for loop:
  - A for loop can also be used as a count-controlled loop that iterates over a range of integer values.

```
i = 1
while i < 10 :
    print(i)
    i = i + 1
```

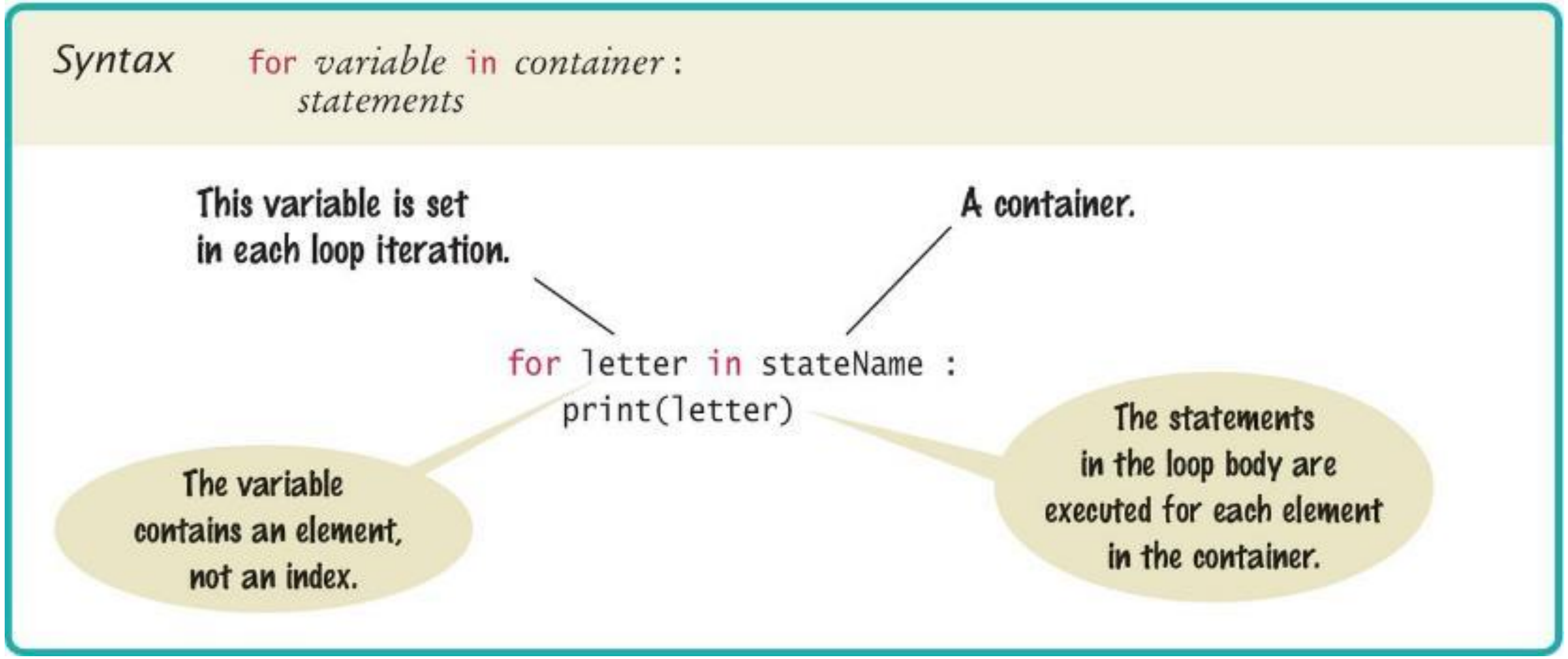
while version

```
for i in range(1, 10) :
    print(i)
```

for version

Syntax of a for Statement (Container)

- Using a for loop to iterate over the contents of a container, an element at a time.



Syntax

```
for variable in container :
    statements
```

```
for letter in stateName :
    print(letter)
```

This variable is set in each loop iteration.

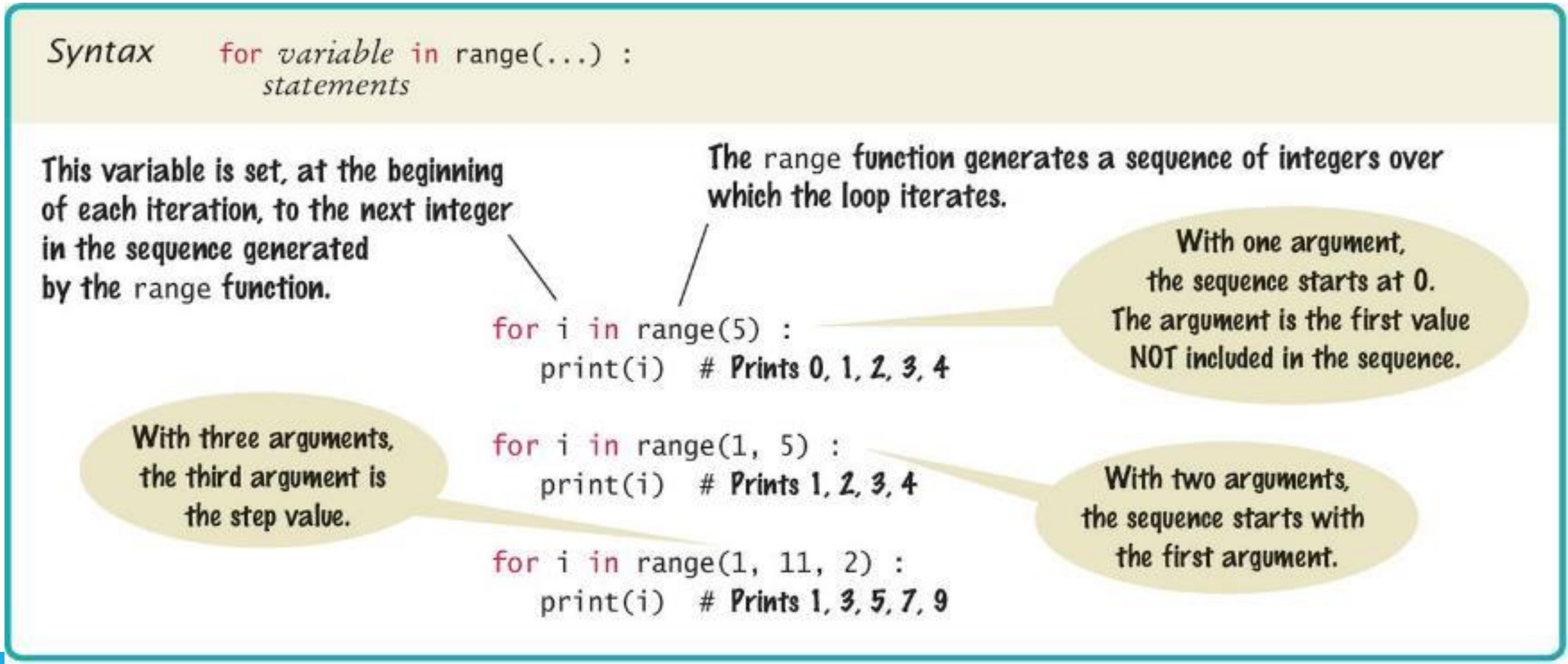
A container.

The variable contains an element, not an index.

The statements in the loop body are executed for each element in the container.

Syntax of a for Statement (Range)

- You can use a for loop as a count-controlled loop to iterate over a range of integer values
- The `range` function generates a sequence of integers that can be used with the for loop



Syntax

```
for variable in range(...) :
    statements
```

This variable is set, at the beginning of each iteration, to the next integer in the sequence generated by the range function.

The range function generates a sequence of integers over which the loop iterates.

```
for i in range(5) :
   print(i)   # Prints 0, 1, 2, 3, 4
```

With one argument, the sequence starts at 0. The argument is the first value NOT included in the sequence.

```
for i in range(1, 5) :
   print(i)   # Prints 1, 2, 3, 4
```

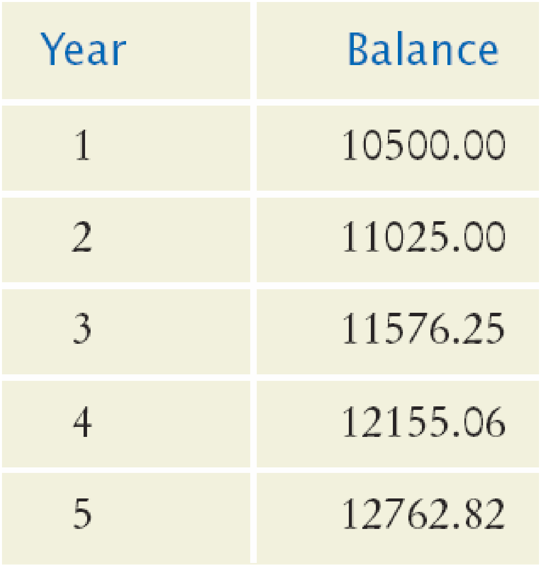
With two arguments, the sequence starts with the first argument.

```
for i in range(1, 11, 2) :
   print(i)   # Prints 1, 3, 5, 7, 9
```

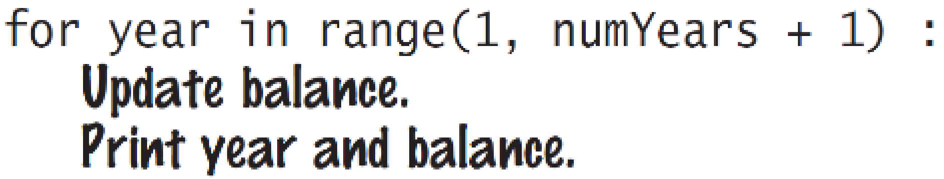
With three arguments, the third argument is the step value.

Carefully study the `range()` parameters

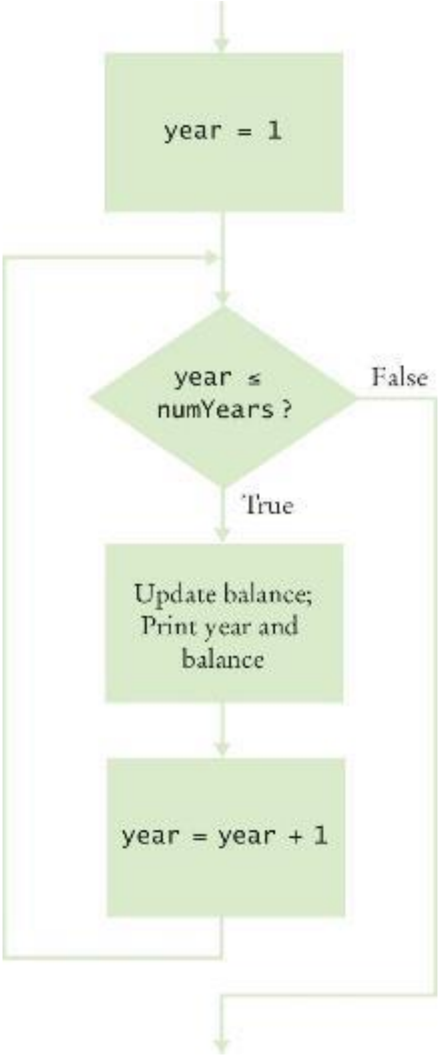
- Print the balance at the end of each year for a number of years



Year	Balance
1	10500.00
2	11025.00
3	11576.25
4	12155.06
5	12762.82



```
for year in range(1, numYears + 1) :
    Update balance.
    Print year and balance.
```



Good Examples of for Loops

- Keep the loops simple!

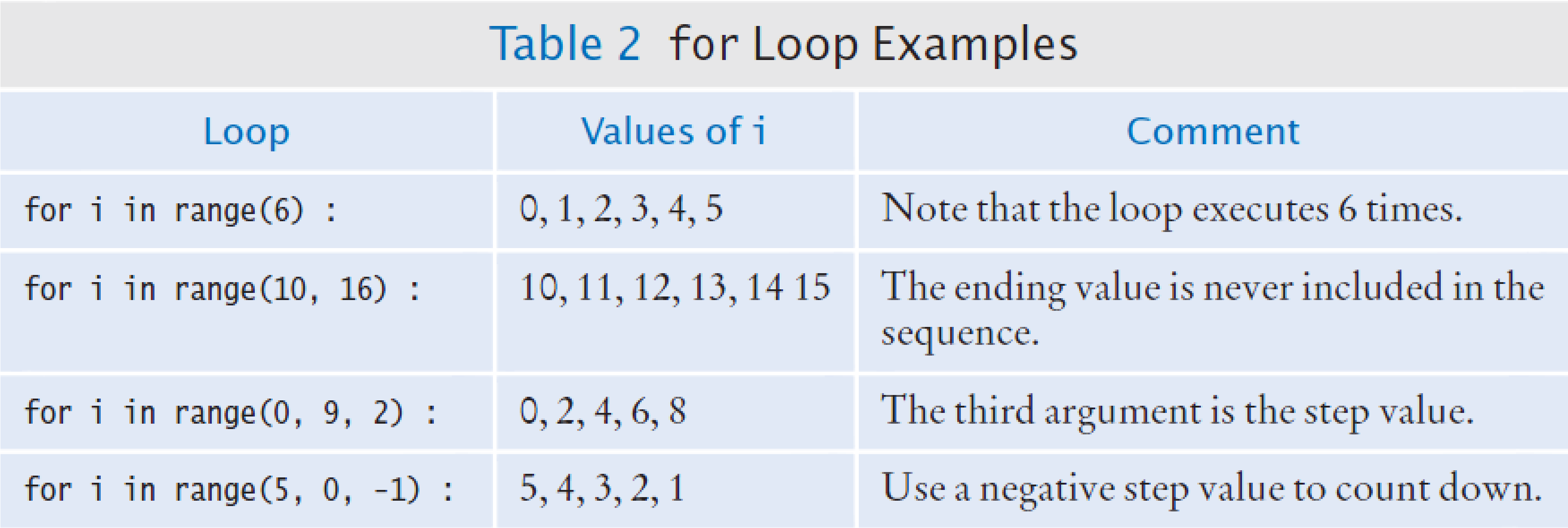
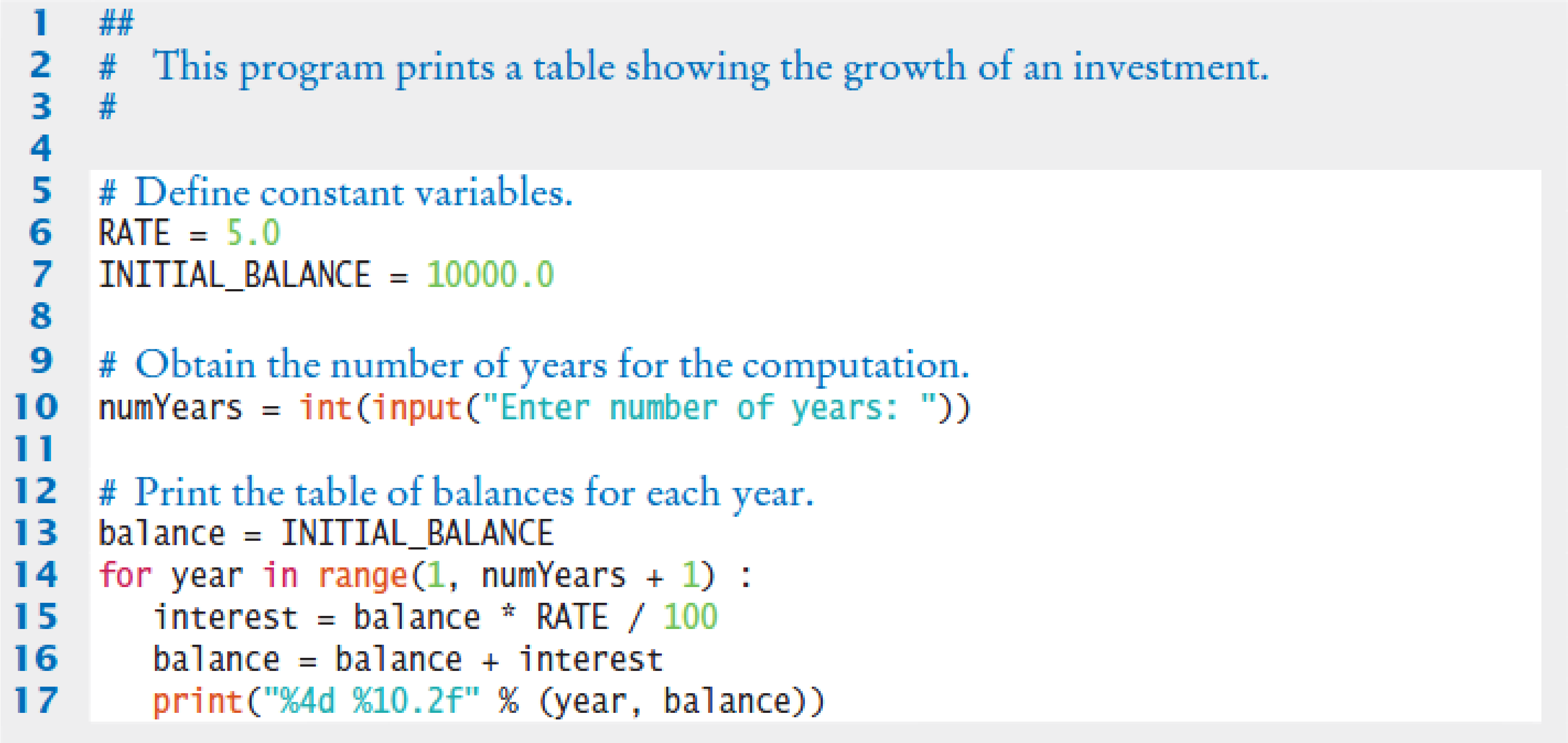


Table 2 for Loop Examples

Loop	Values of i	Comment
`for i in range(6) :`	0, 1, 2, 3, 4, 5	Note that the loop executes 6 times.
`for i in range(10, 16) :`	10, 11, 12, 13, 14 15	The ending value is never included in the sequence.
`for i in range(0, 9, 2) :`	0, 2, 4, 6, 8	The third argument is the step value.
`for i in range(5, 0, -1) :`	5, 4, 3, 2, 1	Use a negative step value to count down.

Investment Example



```
##
#  This program prints a table showing the growth of an investment.
#

# Define constant variables.
RATE = 5.0
INITIAL_BALANCE = 10000.0

# Obtain the number of years for the computation.
numYears = int(input("Enter number of years: "))

# Print the table of balances for each year.
balance = INITIAL_BALANCE
for year in range(1, numYears + 1) :
   interest = balance * RATE / 100
   balance = balance + interest
   print("%4d %10.2f" % (year, balance))
```

Programming Tip

- Finding the correct lower and upper bounds for a loop can be confusing.
  - Should you start at 0 or at 1?
  - Should you use <= b or < b as a termination condition?
- Counting is easier for loops with asymmetric bounds.
  - The following loops are executed b-a times
  - The value a is included, the value b is excluded.

```
int i = a
while i < b :
    . . .
    i = i + 1
```

```
for i in range(a, b) :
    . . .
```

Programming Tip

- The loop with symmetric bounds (“<=”), is executed b-a+1 times.
  - That “+1” is the source of many programming errors.

```
i = a
while i <= b :
  . . .
  i = i + 1
```

```
# For  this version of the loop the
‘+1’ is very noticeable!
for year in range(1, numYears + 1) :
```

Summary of the for Loop

- `for` loops are very powerful
- The `for` loop can be used to iterate over the contents of any container, which is an object that contains or stores a collection of elements
  - A string is a container that stores the collection of characters in the string.
- A for loop can also be used as a **count-controlled** loop that iterates over a **range** of integer values.

Steps to Write a Loop

- Planning:
  - Decide what work to do inside the loop
  - Specify the loop condition
  - Determine loop type
  - Setup variables before the first loop
  - Process results when the loop is finished
  - Trace the loop with typical examples
- Coding:
  - Implement the loop in Python

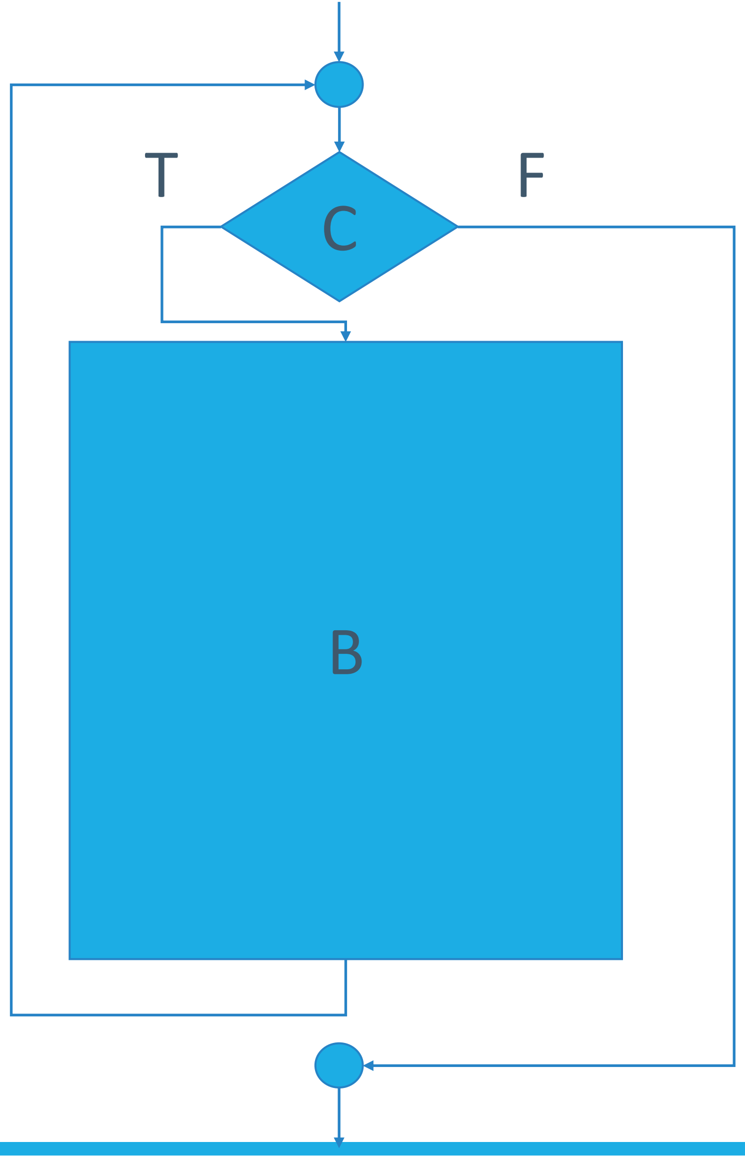
Nested Loops

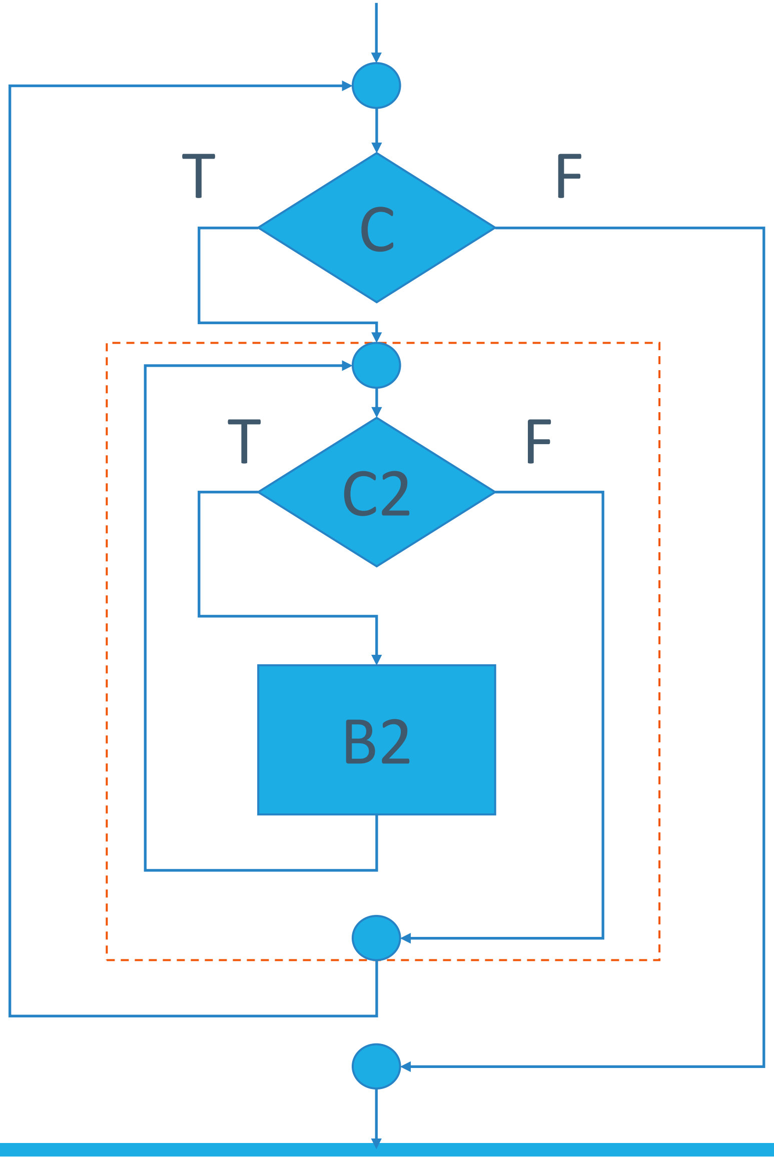
📘 4.7

Loops Inside of Loops

- We know how to nest `if` statements for making complex decisions
  - Remember: nesting requires to indent the code block
- Complex problems sometimes require a **nested loop**, one loop nested inside another loop
  - The nested loop will be indented inside the code block of the first loop
- A good example of using nested loops is when you are processing cells in a table (or matrix)
  - The outer loop iterates over all of the rows in the table
  - The inner loop processes the columns in the current row

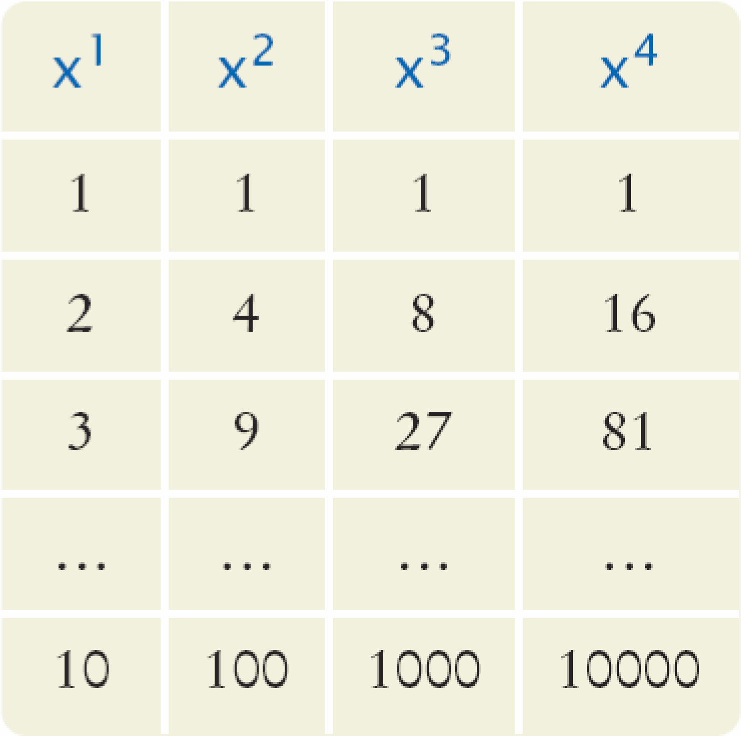
Nested while loops





Our Example Problem Statement

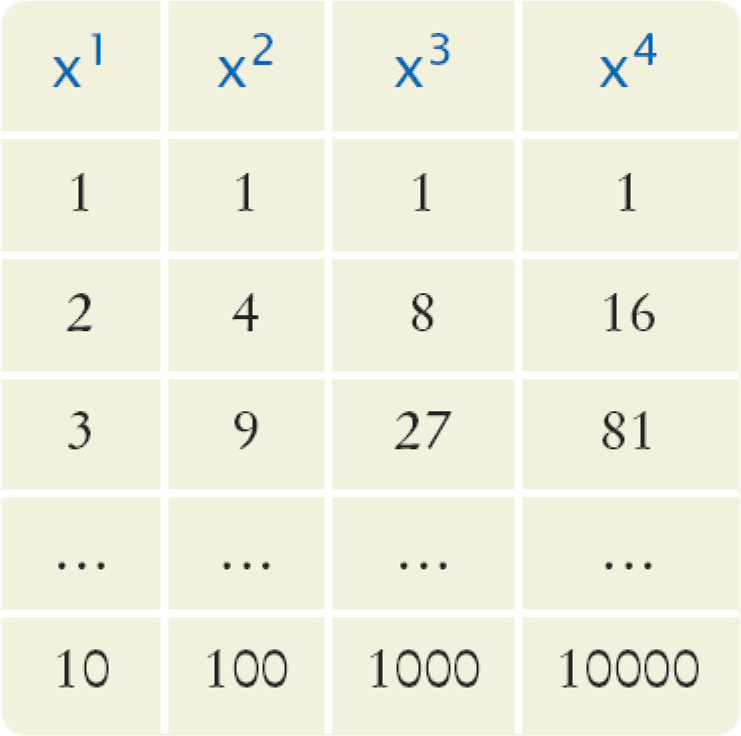
- Print a Table Header that contains x^1, x^2, x^3, and x^4
- Print a Table with four columns and ten rows that contain the powers of x^1, x^2, x^3, and x^4 for x = 1 to x = 10



x^1	x^2	x^3	x^4
1	1	1	1
2	4	8	16
3	9	27	81
...	...	...	...
10	100	1000	10000

Applying Nested Loops

- How would you print a table with rows and columns?
  - Print top line (header)
    - Use a for loop
  - Print table body…
    - How many rows are in the table?
    - How many columns in the table?
  - Loop per row
    - Loop per column
- In our example there are:
  - Four columns in the table
  - Ten rows in the table



x^1	x^2	x^3	x^4
1	1	1	1
2	4	8	16
3	9	27	81
…	…	…	…
10	100	1000	10000

Pseudocode to Print the Table

- Print the table header

```
for x from 1 to 10
    print a new table row
    print a new line
```

- How do we print a table row?

```
for n from 1 to 4
    print $x^n$
```

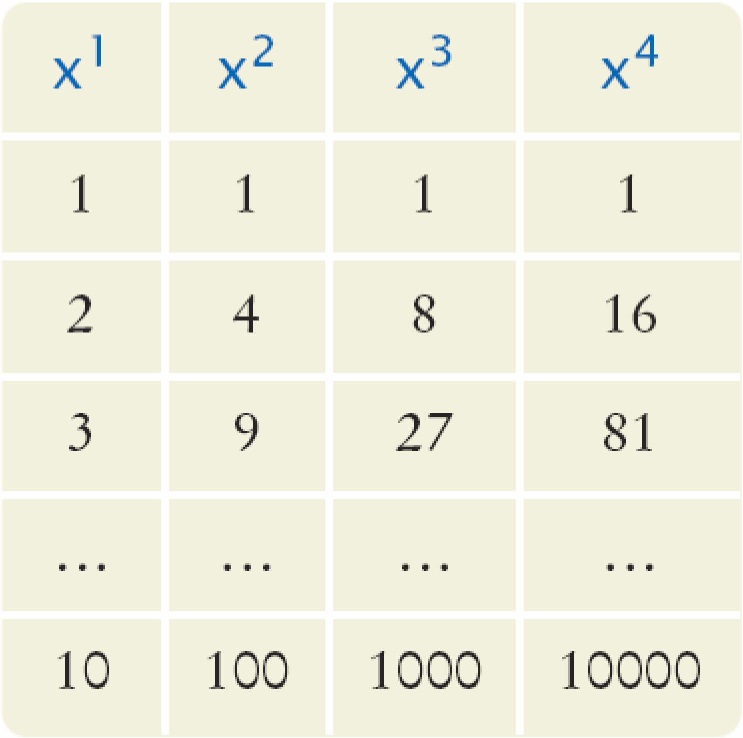
- We have to place this loop inside the previous loop
  - The inner loop is “nested” inside the outer loop

Pseudocode to Print the Table

```
print the table header

for x from 1 to 10
    for n from 1 to 4
        print $x^n$
    print a new line
```

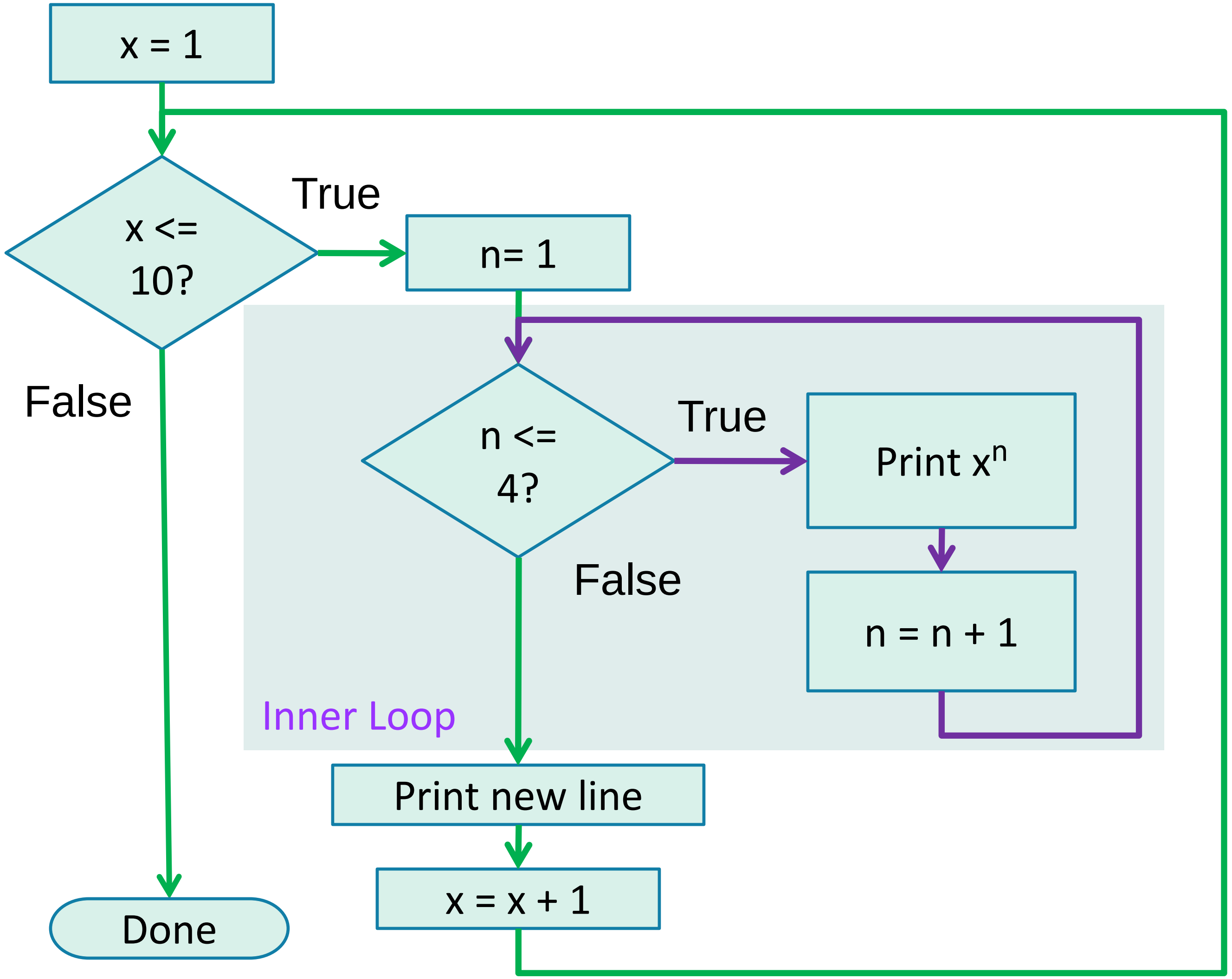
n →

x ↓

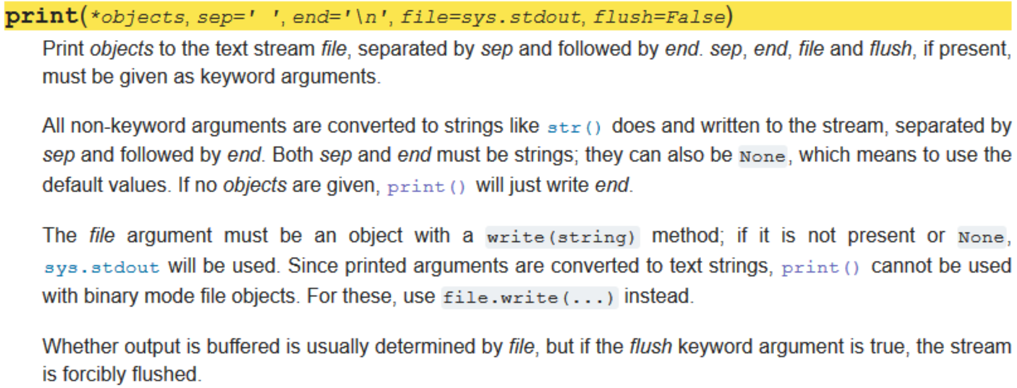


x^1	x^2	x^3	x^4
1	1	1	1
2	4	8	16
3	9	27	81
…	…	…	…
10	100	1000	10000

Flowchart of a Nested Loop



Optional parameters of the `print` function



print(**objects, sep=' ', end='\n', file=sys.stdout, flush=False*)

Print *objects* to the text stream *file*, separated by *sep* and followed by *end*. *sep*, *end*, *file* and *flush*, if present, must be given as keyword arguments.

All non-keyword arguments are converted to strings like `str()` does and written to the stream, separated by *sep* and followed by *end*. Both *sep* and *end* must be strings; they can also be `None`, which means to use the default values. If no *objects* are given, `print()` will just write *end*.

The *file* argument must be an object with a `write(string)` method; if it is not present or `None`, `sys.stdout` will be used. Since printed arguments are converted to text strings, `print()` cannot be used with binary mode file objects. For these, use `file.write(...)` instead.

Whether output is buffered is usually determined by *file*, but if the *flush* keyword argument is true, the stream is forcibly flushed.

https://docs.python.org/3/library/functions.html#print

https://realpython.com/python-print/

- sep=
  - Defines the separator that will be inserted if you print several valued
  - Default: space
  - `print(hour, min, sec, sep=':')`
- end=
  - Defines what to print at the end of each line
  - Default: newline
  - `print('Hello', end='')`

Printing in the same line

- We may use the 'end' optional parameter, so that `print` does not start a new line after the arguments are displayed
- This is used when we want to print items on the same line using multiple print statements
- For example the two statements:

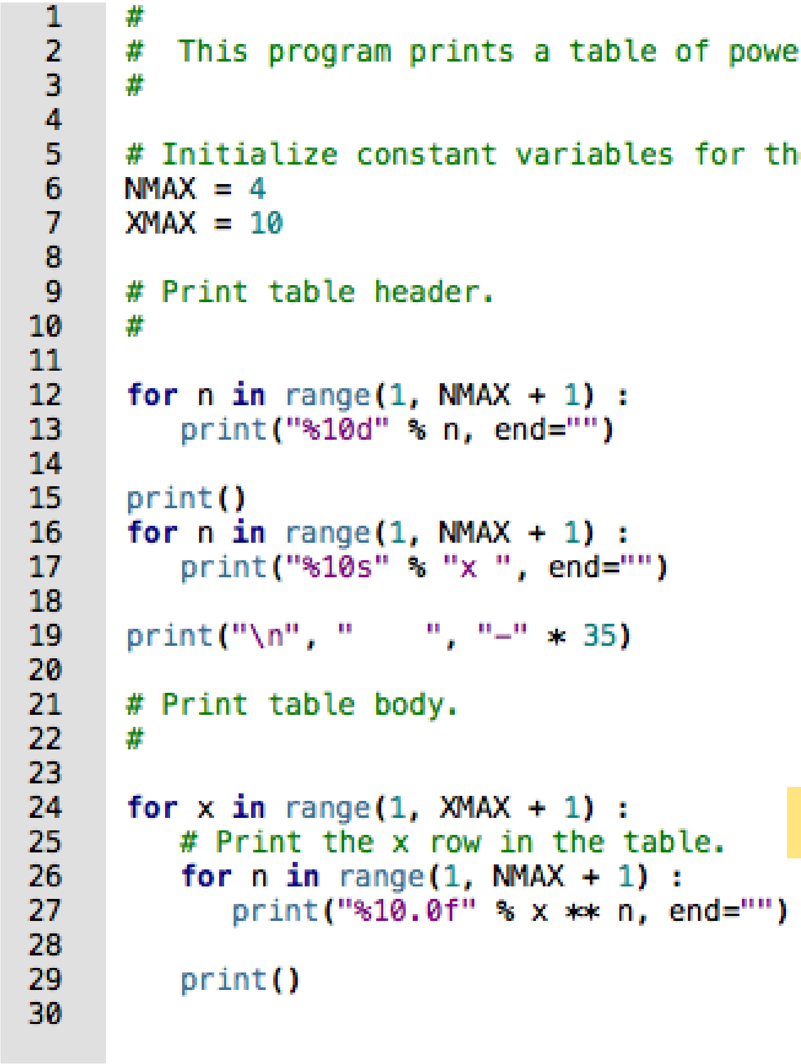
  ```
  print("00", end="")
  print(3 + 4)
  ```

  Produce the output:

  ```
  007
  ```

- Including **`end=""`** as the last argument to the `print` function prints an empty string *after* the arguments, instead of a new line
- The output of the next `print` function starts on the same line

Powertable.py



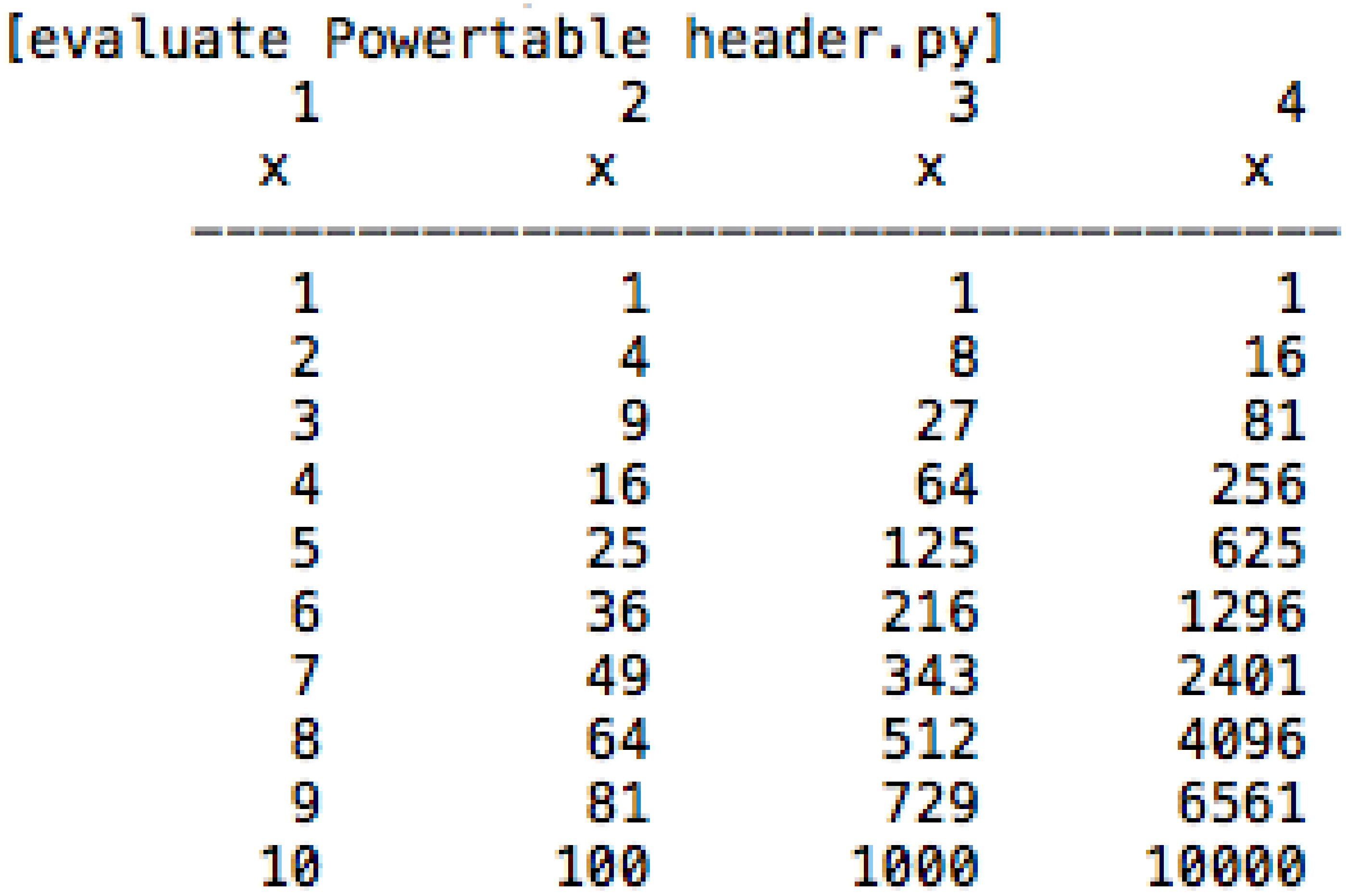
```
#
#  This program prints a table of powers of x.
#

# Initialize constant variables for the max ranges.
NMAX = 4
XMAX = 10

# Print table header.
#

for n in range(1, NMAX + 1) :
   print("%10d" % n, end="")

print()
for n in range(1, NMAX + 1) :
   print("%10s" % "x ", end="")

print("\n", "    ", "-" * 35)

# Print table body.
#

for x in range(1, XMAX + 1) :
   # Print the x row in the table.
   for n in range(1, NMAX + 1) :
      print("%10.0f" % x ** n, end="")

   print()

```

The **end=“”** suppresses the new line, so the numbers are all printed on the same line

Body of outer loop, x = 1 ➔ 10

Body of inner loop, n = 1 ➔ 4

The Results



```
[evaluate Powertable header.py]
         1         2         3         4
        x         x         x         x
      ------------------------------------
         1         1         1         1
         2         4         8        16
         3         9        27        81
         4        16        64       256
         5        25       125       625
         6        36       216      1296
         7        49       343      2401
         8        64       512      4096
         9        81       729      6561
        10       100      1000     10000
```

Exercise

- Open the program:
    - powertable.py
- Run the program and review the results
- Make the following changes:
    - Change the value of NMAX to 6 and run the program
    - What changes in the table?
    - Change the value of NMAX back to 4
    - Change the value of XMAX to 4
    - What changes in the table?

Nested Loop Examples

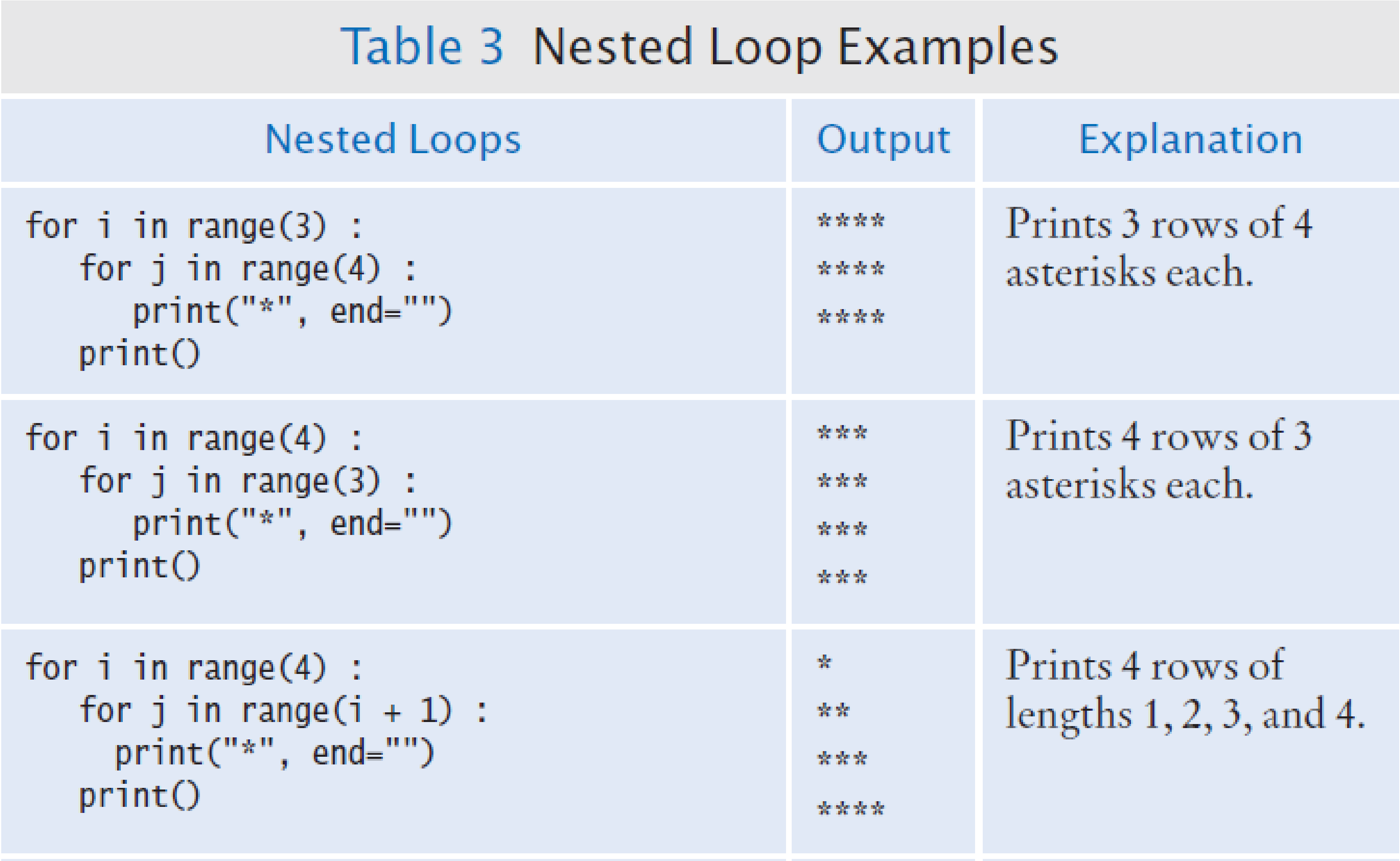


Table 3 Nested Loop Examples

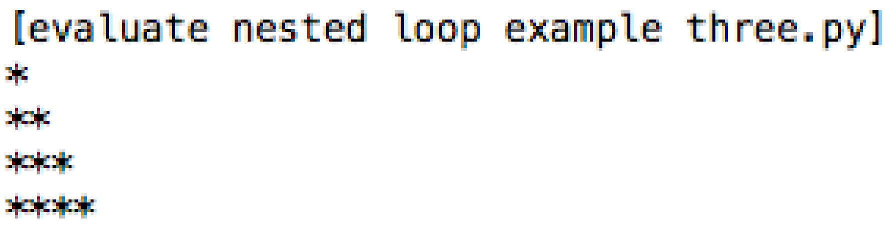
Nested Loops	Output	Explanation

`for i in range(3) :`
`   for j in range(4) :`
`      print("*", end="")`
`   print()`
	`****`
	`****`
	`****`
		Prints 3 rows of 4 asterisks each.

`for i in range(4) :`
`   for j in range(3) :`
`      print("*", end="")`
`   print()`
	`***`
	`***`
	`***`
	`***`
		Prints 4 rows of 3 asterisks each.

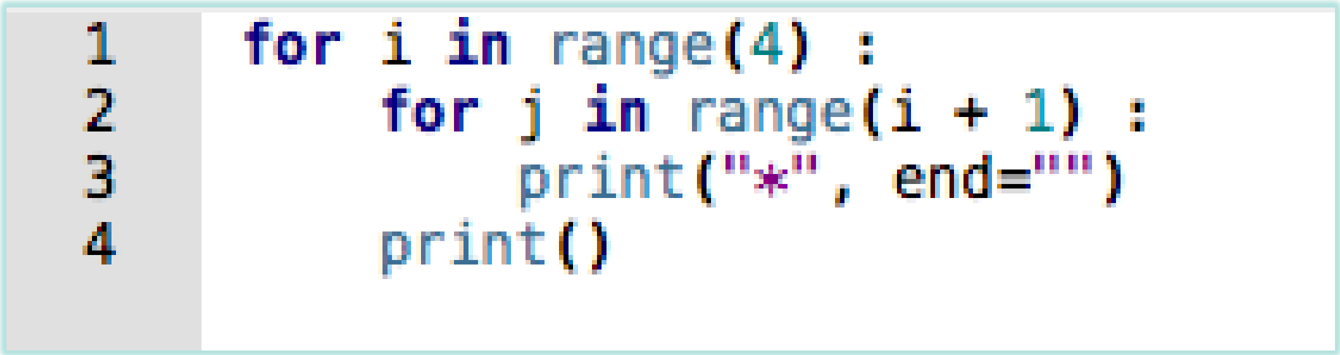
`for i in range(4) :`
`   for j in range(i + 1) :`
`     print("*", end="")`
`   print()`
	`*`
	`**`
	`***`
	`****`
		Prints 4 rows of lengths 1, 2, 3, and 4.

Hand Tracing the Loop



```
[evaluate nested loop example three.py]
*
**
***
****
```

- i will have the values:
  - 0, 1, 2, 3 – So we will have four lines of stars
- j will have the values
  - 0 - So we will have one star
  - 0, 1 - So we will have two stars
  - 0, 1, 2 - So we will have three stars
  - 0, 1, 2, 3 - So we will have four stars



```python
for i in range(4) :
    for j in range(i + 1) :
        print("*", end="")
    print()
```

Nested Loop Examples (2)

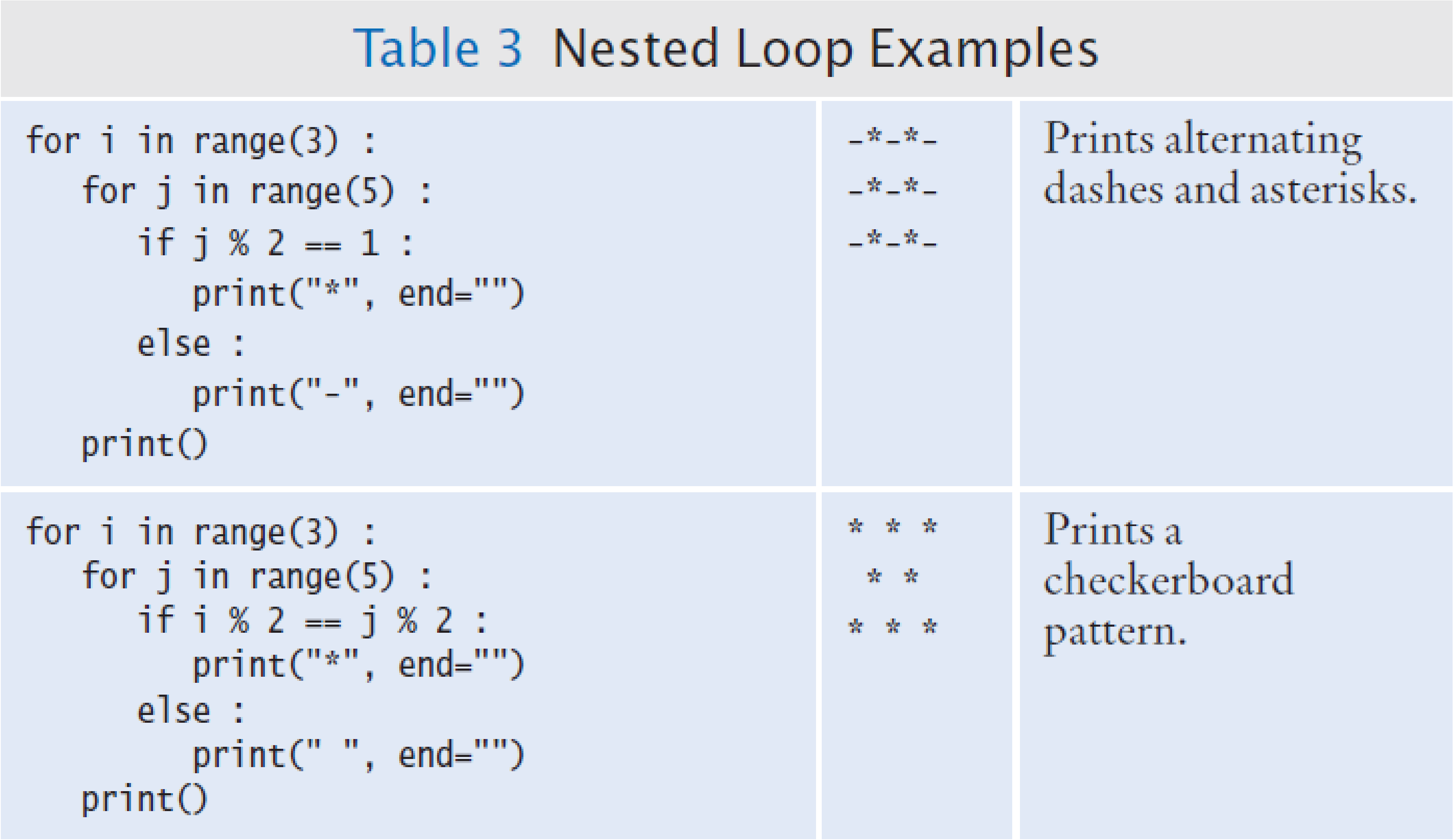


Table 3 Nested Loop Examples

`for i in range(3) :`
`   for j in range(5) :`
`      if j % 2 == 1 :`
`         print("*", end="")`
`      else :`
`         print("-", end="")`
`   print()`
	`-*-*-`
	`-*-*-`
	`-*-*-`
		Prints alternating dashes and asterisks.

`for i in range(3) :`
`   for j in range(5) :`
`      if i % 2 == j % 2 :`
`         print("*", end="")`
`      else :`
`         print(" ", end="")`
`   print()`
	`* * *`
	` * * `
	`* * *`
		Prints a checkerboard pattern.

Second Problem Statement

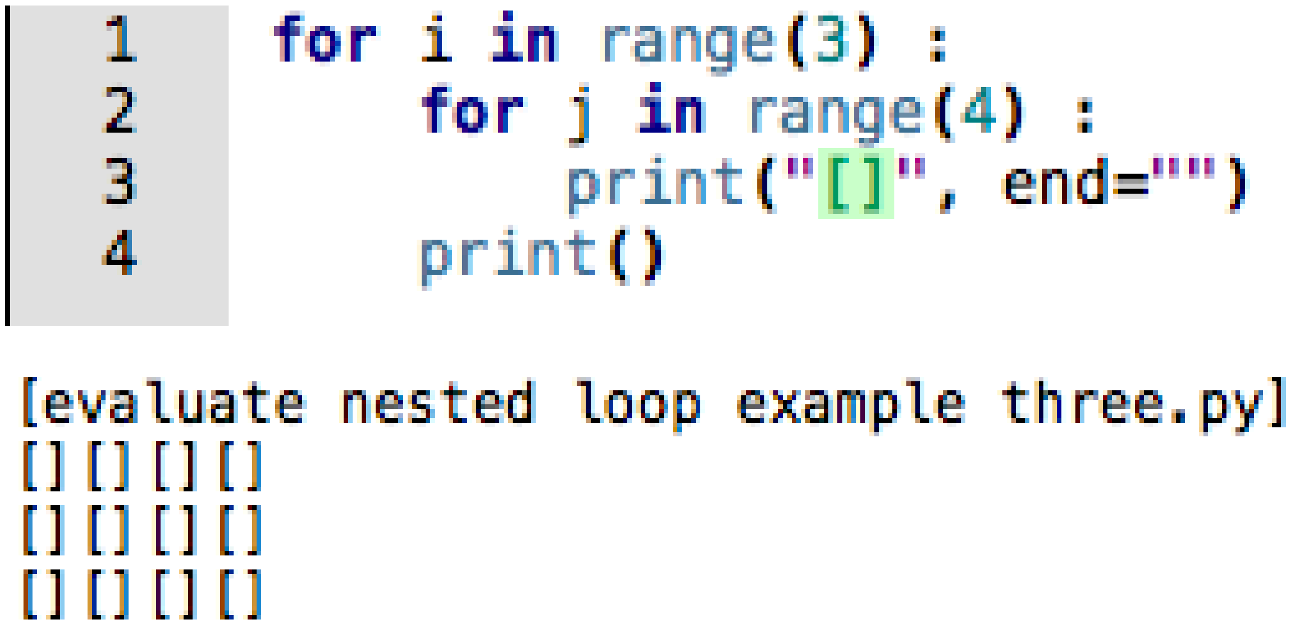
- Print the following pattern of brackets:

```
[][][][]
[][][][]
[][][][]
```

- The pattern consists of:
  - Three rows
  - Each row has four pairs of brackets
- What do we know?
  - We need two nested loops
    - The first loop (the outer loop) will print each of the three rows
    - The second loop (the inner loop) will print the four pairs of brackets

Pseudocode, Results

```
For i = 0 to 2    # 3 rows
  For j = 0 to 3        # 4 cols
    Print “[]”
  Print a new line
```



```python
for i in range(3) :
    for j in range(4) :
        print("[]", end="")
    print()
```

```
[evaluate nested loop example three.py]
[][][][]
[][][][]
[][][][]
```

Exercise: Exam Averages

Exam Averages - Problem Statement

- It is common to repeatedly read and process multiple groups of values:
  - Write a program that can compute the average exam grade for multiple students.
  - Each student has the same number of exam grades
  - Prompt the user for the number of exams
  - When you finish a student, prompt the user to see if there are more students to process
- What do we know?
- What do we need to compute?
- What is our algorithm / approach?

Step One: Understand the Problem

- To compute the average grade for a student, we must read and tally all of the grades for that student
  - We can use a loop to do this. (we have working code to do this portion)
- We need to compute grades for multiple students
  - That implies a set of nested Loops
    - The outer loop processes each student
    - The inner loop process the specific student’s grades

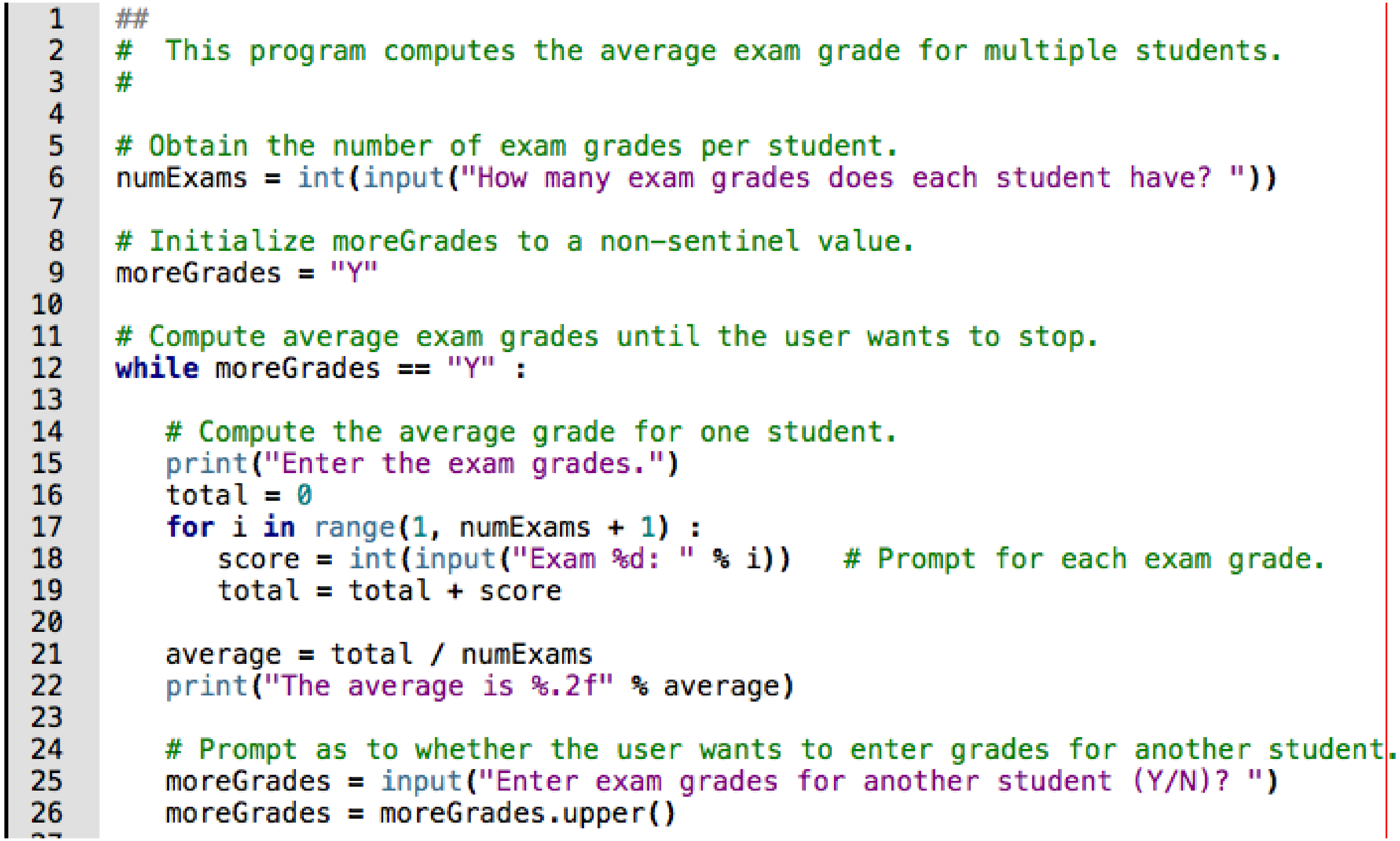
Step Two

- Compute the grade for one student
- Set up the variables and loop
- We know how many grades to process, so we can use a count-controlled loop
- total score = 0
- For i in range (1, number of exams + 1) :
    - Read the next exam score
    - Add the exam score to the total score
- Compute the exam average
- Print the exam average

Step Three

- Repeat the process for each student
- Since we don’t know how many students there are, we will use a while loop with a sentinel value
  - For simplicity we will use “Y” as the sentinel value (Y=yes, N=no)

Step Four: Translate to Python



```
##
#  This program computes the average exam grade for multiple students.
#

# Obtain the number of exam grades per student.
numExams = int(input("How many exam grades does each student have? "))

# Initialize moreGrades to a non-sentinel value.
moreGrades = "Y"

# Compute average exam grades until the user wants to stop.
while moreGrades == "Y" :

   # Compute the average grade for one student.
   print("Enter the exam grades.")
   total = 0
   for i in range(1, numExams + 1) :
      score = int(input("Exam %d: " % i))   # Prompt for each exam grade.
      total = total + score

   average = total / numExams
   print("The average is %.2f" % average)

   # Prompt as to whether the user wants to enter grades for another student.
   moreGrades = input("Enter exam grades for another student (Y/N)? ")
   moreGrades = moreGrades.upper()
```

Exam Averages Example

- Open the file:
  - examaverages.py
- Notice that the second loop (the for loop) is nested inside the while loop
  - Study and check the indentation

Application: Random Numbers and Simulations

📘 4.9

Random Numbers/Simulations

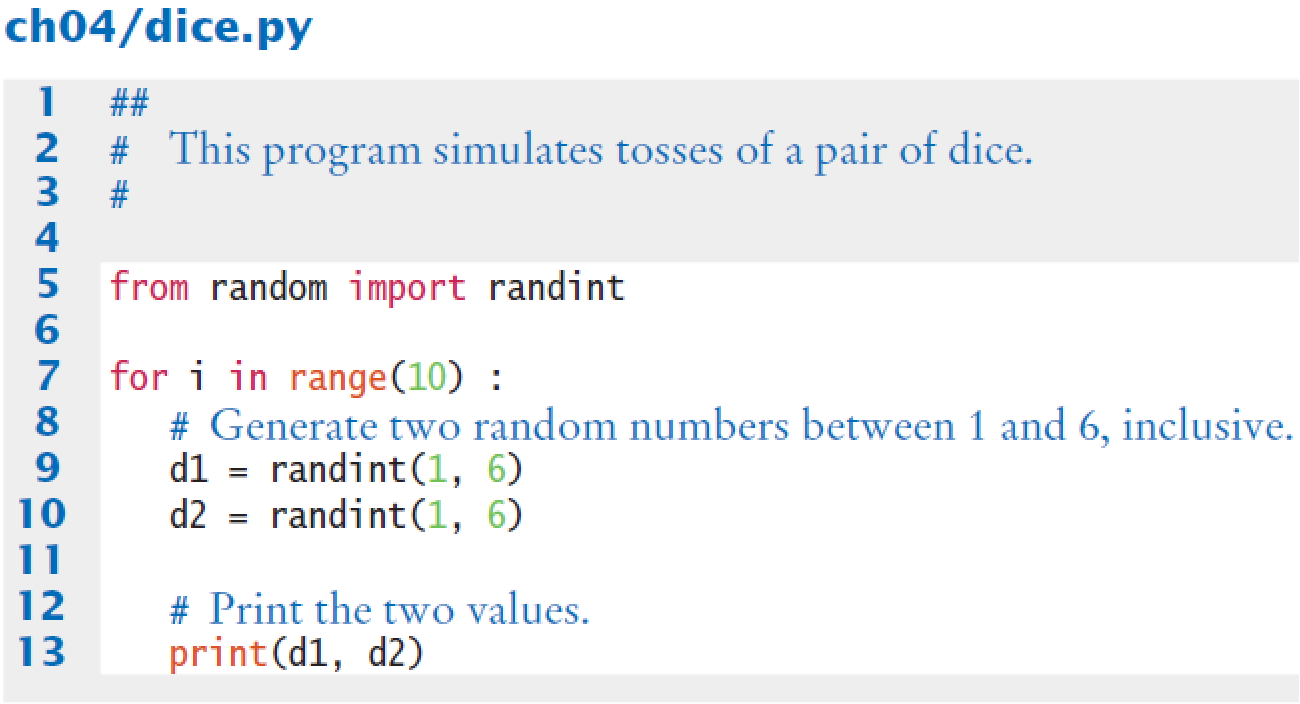
- Games often use random numbers to make things interesting
  - Rolling Dice
  - Spinning a wheel
  - Pick a card
- A simulation usually involves looping through a sequence of events
  - Days
  - Events

Generating Random Numbers

- The Python library has a *random number generator* that produces numbers that **appear** to be random
  - The numbers are not completely random. The numbers are drawn from a sequence of numbers that does not repeat for a long time
  - `random()` returns a number that is >= 0 and < 1
- Random generators are in the 'random' module
  - `from random import random`
  - https://docs.python.org/3/library/random.html
  - https://realpython.com/python-random/#prngs-in-python

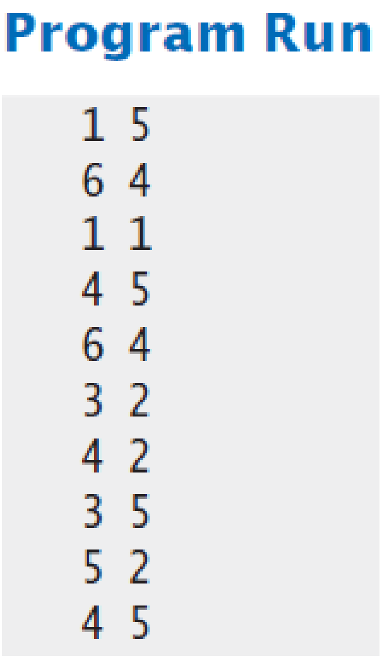
Simulating Die Tosses

- Goal:
  - To generate a random integer in a given range we use the `randint()` function
  - `randint` has two parameters, the range (inclusive) of numbers generated



ch04/dice.py

```python
##
#   This program simulates tosses of a pair of dice.
#

from random import randint

for i in range(10) :
   # Generate two random numbers between 1 and 6, inclusive.
   d1 = randint(1, 6)
   d2 = randint(1, 6)

   # Print the two values.
   print(d1, d2)
```

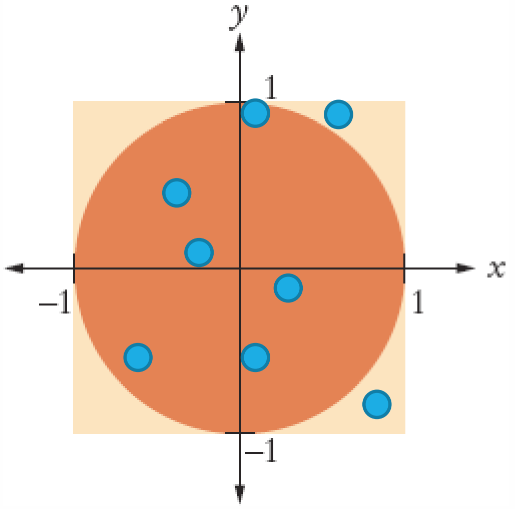


Program Run

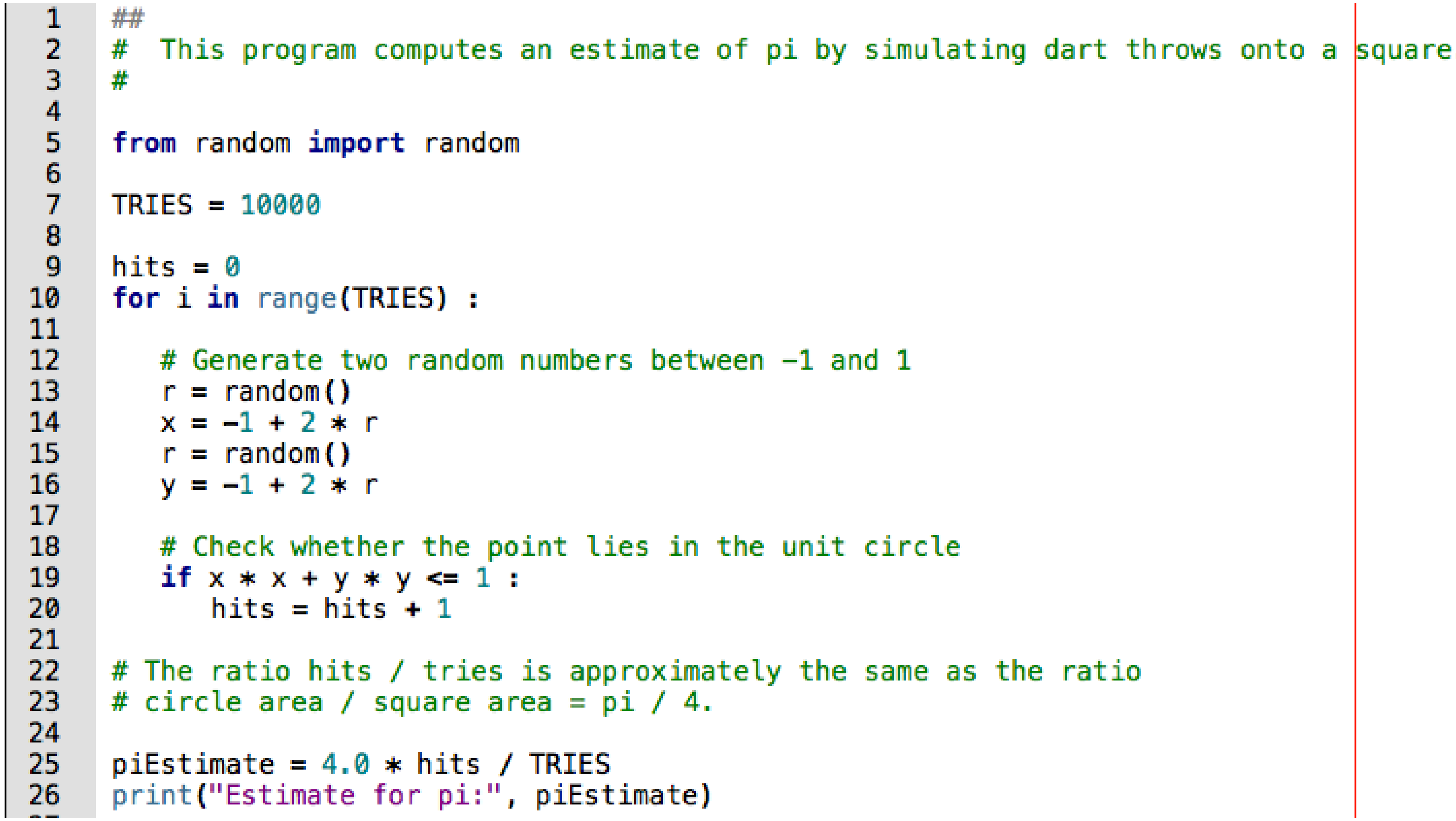
```
1 5
6 4
1 1
4 5
6 4
3 2
4 2
3 5
5 2
4 5
```

The Monte Carlo Method

- Used to find approximate solutions to problems that cannot be precisely solved
- Example: Approximate PI using the relative areas of a circle inside a square
  - Uses simple arithmetic
  - Generate random points in [-1,1]x[-1,1]
  - `Hits` are inside circle, i.e. $x^2+y^2 \leqslant 1$
  - `Tries` are total number of tries
  - `Ratio` is 4 x Hits / Tries
    - N.B. 4 is the area of the square

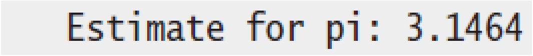


Monte Carlo Example



```
##
#  This program computes an estimate of pi by simulating dart throws onto a square
#

from random import random

TRIES = 10000

hits = 0
for i in range(TRIES) :

   # Generate two random numbers between -1 and 1
   r = random()
   x = -1 + 2 * r
   r = random()
   y = -1 + 2 * r

   # Check whether the point lies in the unit circle
   if x * x + y * y <= 1 :
      hits = hits + 1

# The ratio hits / tries is approximately the same as the ratio
# circle area / square area = pi / 4.

piEstimate = 4.0 * hits / TRIES
print("Estimate for pi:", piEstimate)
```

Program Run



```
Estimate for pi: 3.1464
```

Processing Strings

📘 4.8

Processing Strings

- A common use of loops is to process or evaluate Strings.
- For example, you may need to count the number of occurrences of one or more characters in a string or verify that the contents of a string meet certain criteria.

String Processing Examples

- Counting Matches
- Finding All Matches
- Finding the First or Last Match
- Validating a String
- Building a New String

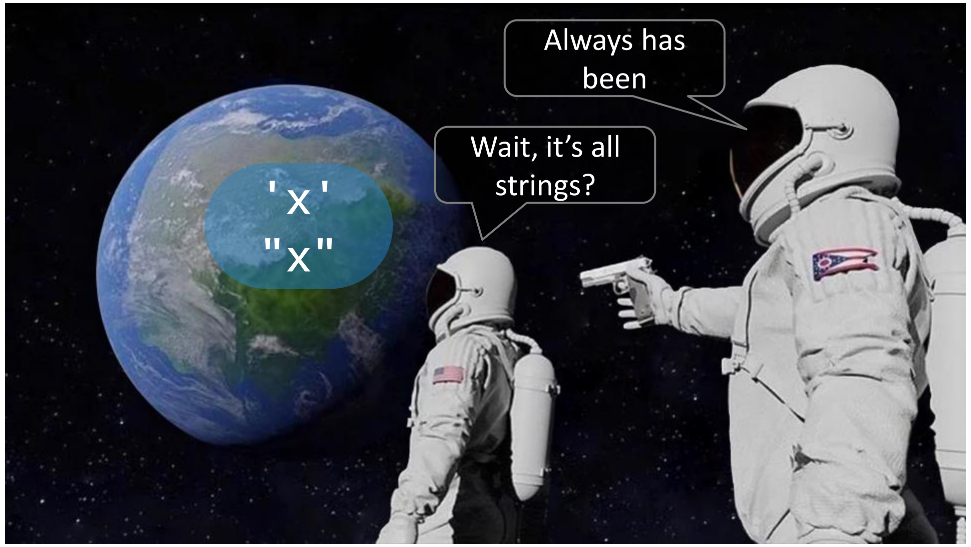
Counting Matches

- Suppose you need to *count the number of uppercase letters* contained in a string.
- We can use a `for` loop to check each character in the string to see if it is upper case
- The loop below sets the variable `ch` equal to each successive character in the string
- Each pass through the loop tests the next character in the string to see if it is uppercase

```
uppercase = 0
for ch in string :
   if ch.isupper() :
      uppercase = uppercase + 1
```

Note

- `for ch in string :`
- At each iteration, ch assumes the value of the next character in the string
- In Python, ch is itself a String (of length 1)
  - There is no “character” or “char” type
  - Big difference w.r.t. C/C++/Java



Counting Vowels

- Suppose you need to count the vowels within a string
- We can use a `for` loop to check each character in the string to see if it is in the string of vowels “`aeiuo`”
- The loop below sets the variable `ch` equal to each successive character in the string
- Each pass through the loop tests the lower case of the next character in the string to see if it is included in the string “aeiou” (add accented vowels, if you like)

```
vowels = 0
for char in word :
   if ch.lower() in "aeiou" :
      vowels = vowels + 1
```

Finding All Matches

- When we need to examine every character in a string, independent of its position we can use a `for` statement to examine each character

- If we need to print the position of each uppercase letter in a sentence we can iterate over the positions (using for-range) thus look up and test the character at each position
  - If uppercase, print the position

- We set the range to be the length of the string
  - We test each character
  - If uppercase print `i`, its position in the string

```
sentence = input("Enter a sentence: ")
for i in range(len(sentence)) :
   if sentence[i].isupper() :
      print(i) # the position, not the letter
```

Finding the First Match

- This example finds the position of the first digit in a string.

```
found = False
position = 0
while not found and position < len(string) :
   if string[position].isdigit() :
      found = True
   else :
      position = position + 1

if found :
   print("First digit occurs at position", position)
else :
   print("The string does not contain a digit.")
```

Finding the Last Match

- Here is a loop that finds the position of the last digit in the string.
- This approach uses a `while` loop to start at the last character in a string and test each value moving towards the start of the string
  - Position is set to the length of the string - 1
  - If the character is not a digit, we decrease position by 1
  - Until we find a digit, or process all the characters

```
found = False
position = len(string) - 1
while not found and position >= 0 :
   if string[position].isdigit() :
      found = True
   else :
      position = position - 1
```

Validating a String

- In the United States, telephone numbers consist of three parts—area code exchange, and line number—which are commonly specified in the form

```
(###)###-####
```

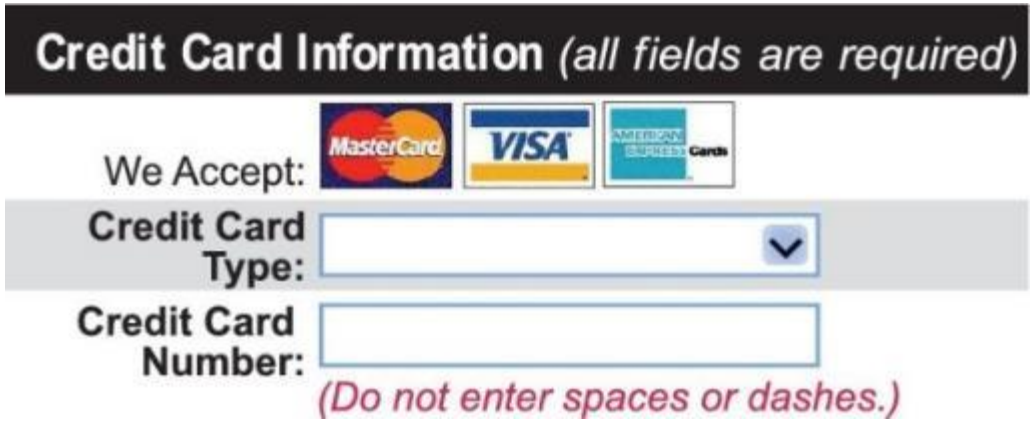
Validating a String (code)

- We can examine a string to ensure that it contains a correctly formatted phone number. (e.g., (703)321-6753)
- The loop test each character to see it it is correct for its position, or a number

```
valid = len(string) == 13 # set valid to True or False
position = 0
while valid and position < len(string) :
   valid = ((position == 0 and string[position] != "(")
       or (position == 4 and string[position] != ")")
       or (position == 8 and string[position] != "-")
       or (position != 0 and position != 4 and position != 8
          and string[position].isdigit())) :
   position = position + 1
```

Building a New String

- One of the minor annoyances of online shopping is that many web sites require you to enter a credit card without spaces or dashes, which makes double-checking the number rather tedious.
- How hard can it be to remove dashes or spaces from a string?



Credit Card Information *(all fields are required)*

We Accept:

Credit Card Type:

Credit Card Number:

(Do not enter spaces or dashes.)

Building a New String (code)

- **The contents of a string cannot be changed.**
  - Python strings are “immutable”
  - But nothing prevents us from building a new string.
- Here is a loop that builds a new string containing a credit card number with spaces and dashes removed:
  - We read the credit card number
  - We initialize a new string to the empty string (`= ""`)
  - We test each character in the user input
    - If the character is not a space or dash we append it to the new string (`+ char`)

```
userInput = input("Enter a credit card number: ")
creditCardNumber = ""
for char in userInput :
   if char != " " and char != "-" :
      creditCardNumber = creditCardNumber + char
```

Application: BlackJack

Blackjack

- Analyze the problem and design an algorithm for a program that plays Bkackjack agains the user. Then, write the corresponding Python code
- The program plays BlackJack. We assume there only one croupier and one player.
- The goal of BlackJack is to get as close as possible to 21, without going over it
    - Compute the sum of the values of the dealt cards

Rules of the game (simplified)

- Phase 1: the computer (croupier) takes a card (for itself) and shows it to the user
- Phase 2: the computer gives 2 cards to the user
- Phase 3: the player may choose to get another card, or to stop
  - This phase repeats until the player stops
  - If the result is >21, the player loses
- Phase 4: if the user didn’t lose, the computer plays, with a simple strategy
  - If the card value is less than 17, then take another card
  - If it’s over 17, stop
  - If it’s over 21, computer loses

End game

- If the croupier goes over 21, the player wins
- If both stop, then the cards must be compared. The player with a higher sum wins the round. The croupier wins in case of parity.

Simplifying Assumptions

- We deal from an infinite pool of cards
  - At every turn, any card had the same probability
- Cards have values from 1 to 11
  - Just deal with integers
  - Don’t care about figures
  - Don’t care about suits ♠ ♥ ♦ ♣

https://en.wikipedia.org/wiki/Playing_cards_in_Unicode

Problem Analysis and Algorihtm Design

Going forward (make it more realistic!)

- Let the players make more than one round (and count points!)
- The Ace 🂡🂱🃁🃑 may have the value 1 or 11, according to the user preference
- When a card has been dealt, it’s no longer in the deck, so its probability decreases

Summary

Summary: Two Types of Loops

- **`while`** loops
- **`for`** loops
- **`while`** loops are very commonly used (general purpose)
- Uses of the **`for`** loop:
  - The **`for`** loop can be used to iterate over the contents of any container.
  - A **`for`** loop can also be used as a count-controlled loop that iterates over a range of integer values.

Summary

- Each loop requires the following steps:
  - Initialization (setup variables to start looping)
  - Condition (test if we should execute loop body)
  - Update (change something each time through)
  - A `for-range` does it automatically, in a `while` it's the programmer's responsibility
- A loop executes instructions repeatedly while a condition is True.
- An off-by-one error is a common error when programming loops.
  - Think through simple test cases to avoid this type of error.

Summary

- A sentinel value denotes the end of a data set, but it is not part of the data.
- You can use a boolean variable to control a loop.
  - Set the variable to `True` before entering the loop
  - Set it to `False` to leave the loop.
- Loops can be used in conjunction with many string processing tasks

Summary

- In a simulation, you use the computer to simulate an activity.
  - You can introduce randomness by calling the random number generator.