Chapter 4: Loops

Chapter 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

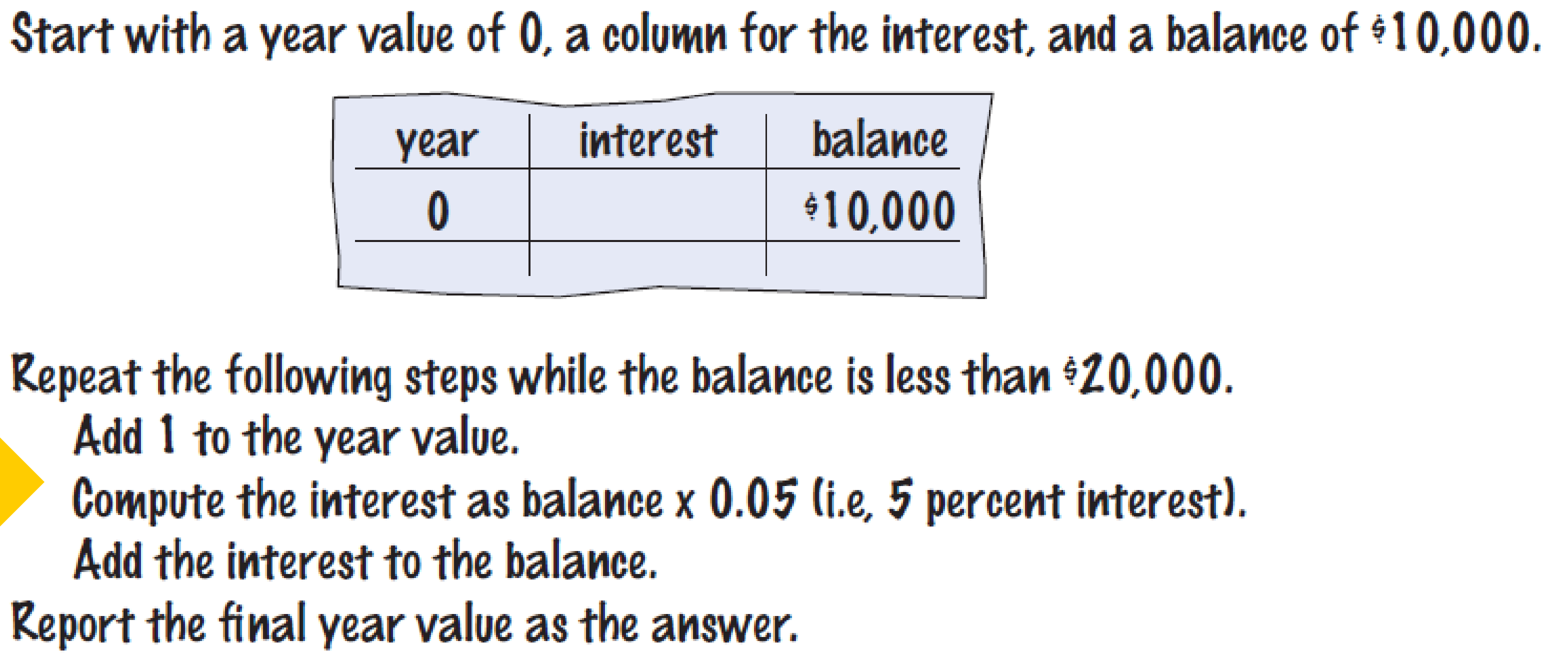
In this chapter, you will learn about loop statements in Python, as well as techniques for writing programs that simulate activities in the real world.

Contents

The **while** Loop

The **while** Loop

- Examples of loop applications
  - Calculating compound interest
  - Simulations, event driven programs
  - Drawing tiles…
- 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

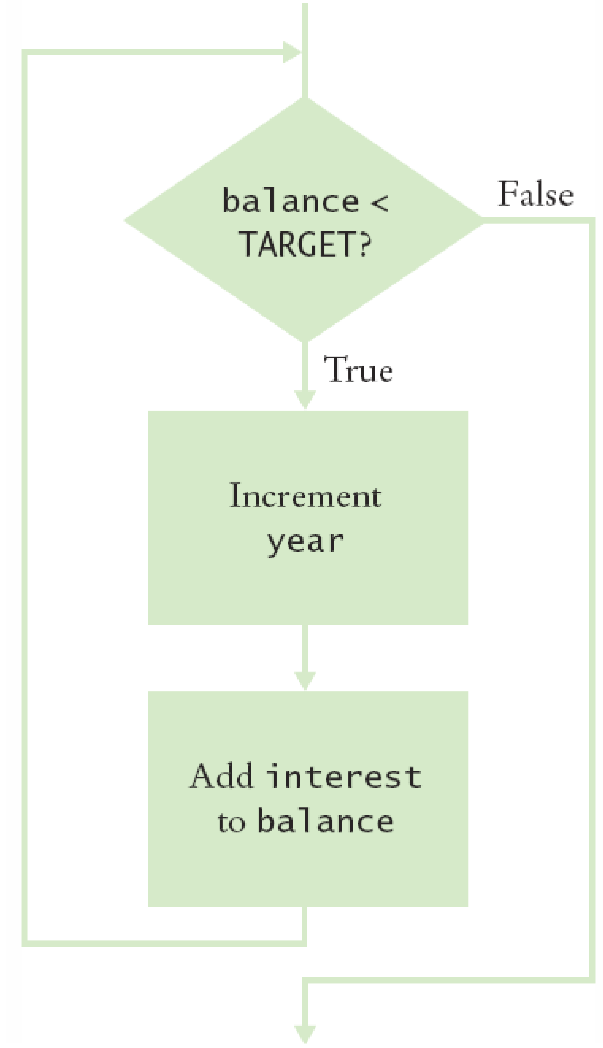
```
Repeat the following steps while the balance is less than $20,000.
    Add 1 to the year value.
    Compute the interest as balance x 0.05 (i.e, 5 percent interest).
    Add the interest to the balance.
Report the final year value as the answer.
```

Steps

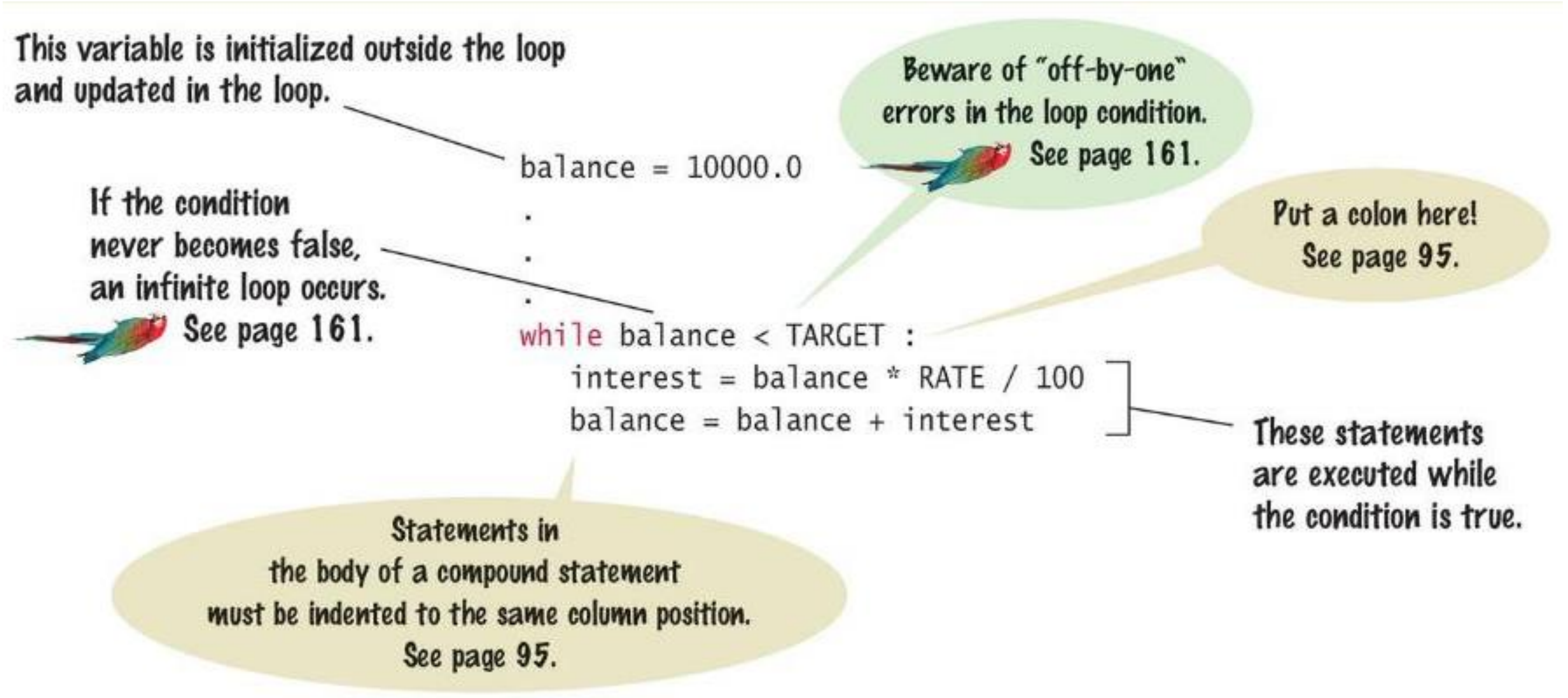
Planning the **while** Loop

```
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 a 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.

Count-Controlled Loops

- A **while** loop that is controlled by a counter

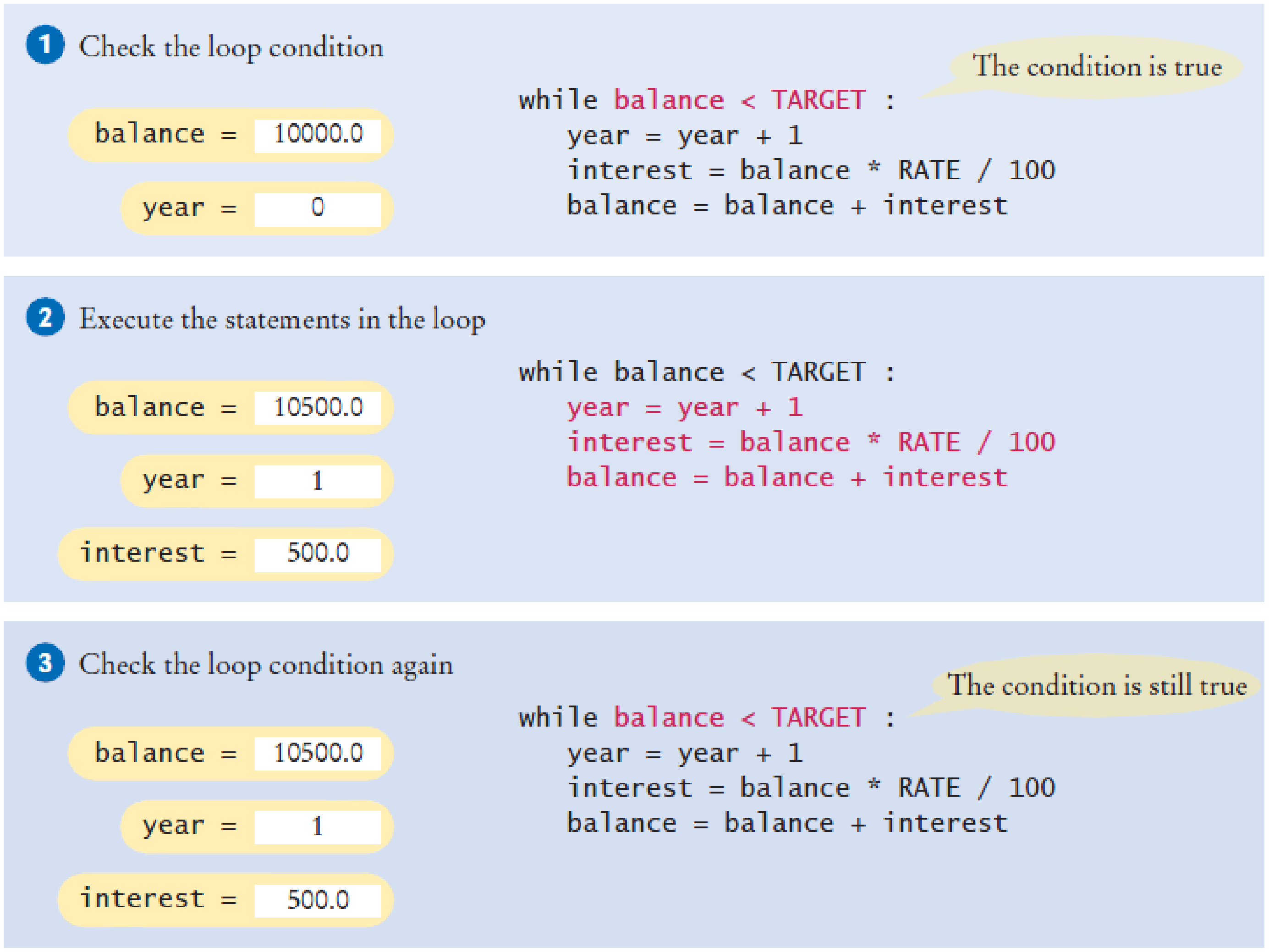
```
counter = 1                                    # Initialize
the counter

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 counter

```
balance = INITIAL_BALANCE         # Initialize the loop variable

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

Execution of the Loop

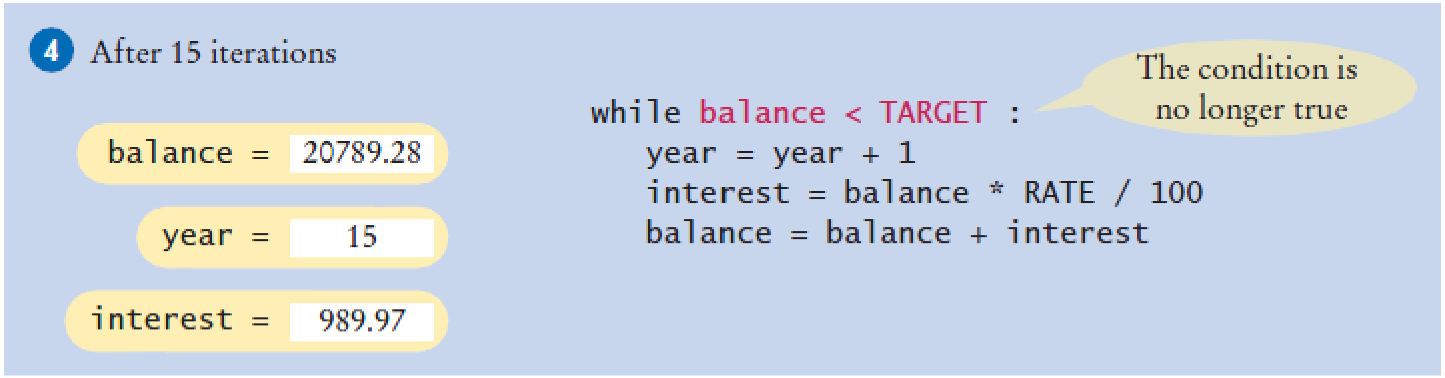

1 Check the loop condition
The condition is true
2 Execute the statements in the loop
3 Check the loop condition again
The condition is still true

```
balance =  10000.0
year =  0

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

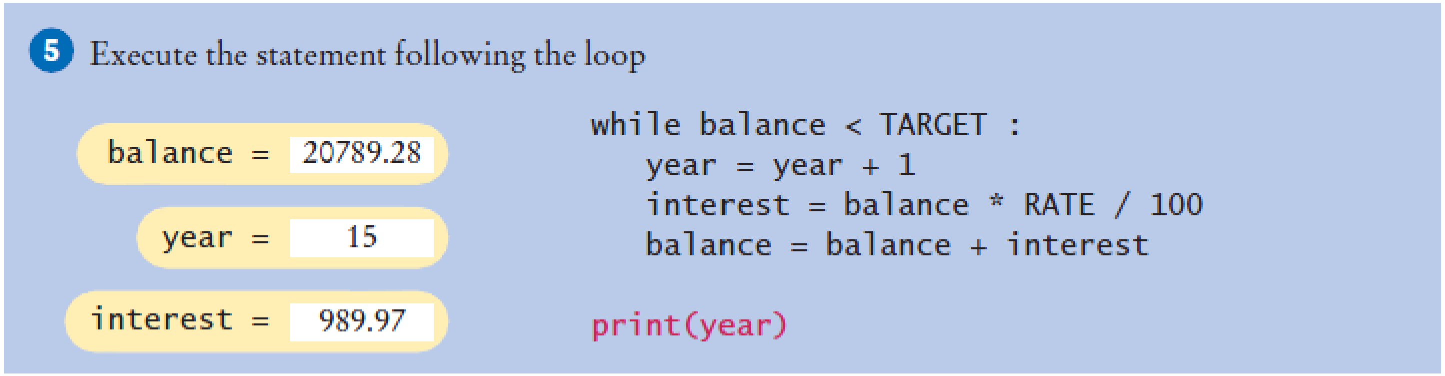
```
balance =  10500.0
year =  1
interest =  500.0

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

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

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

Execution of the Loop (2)

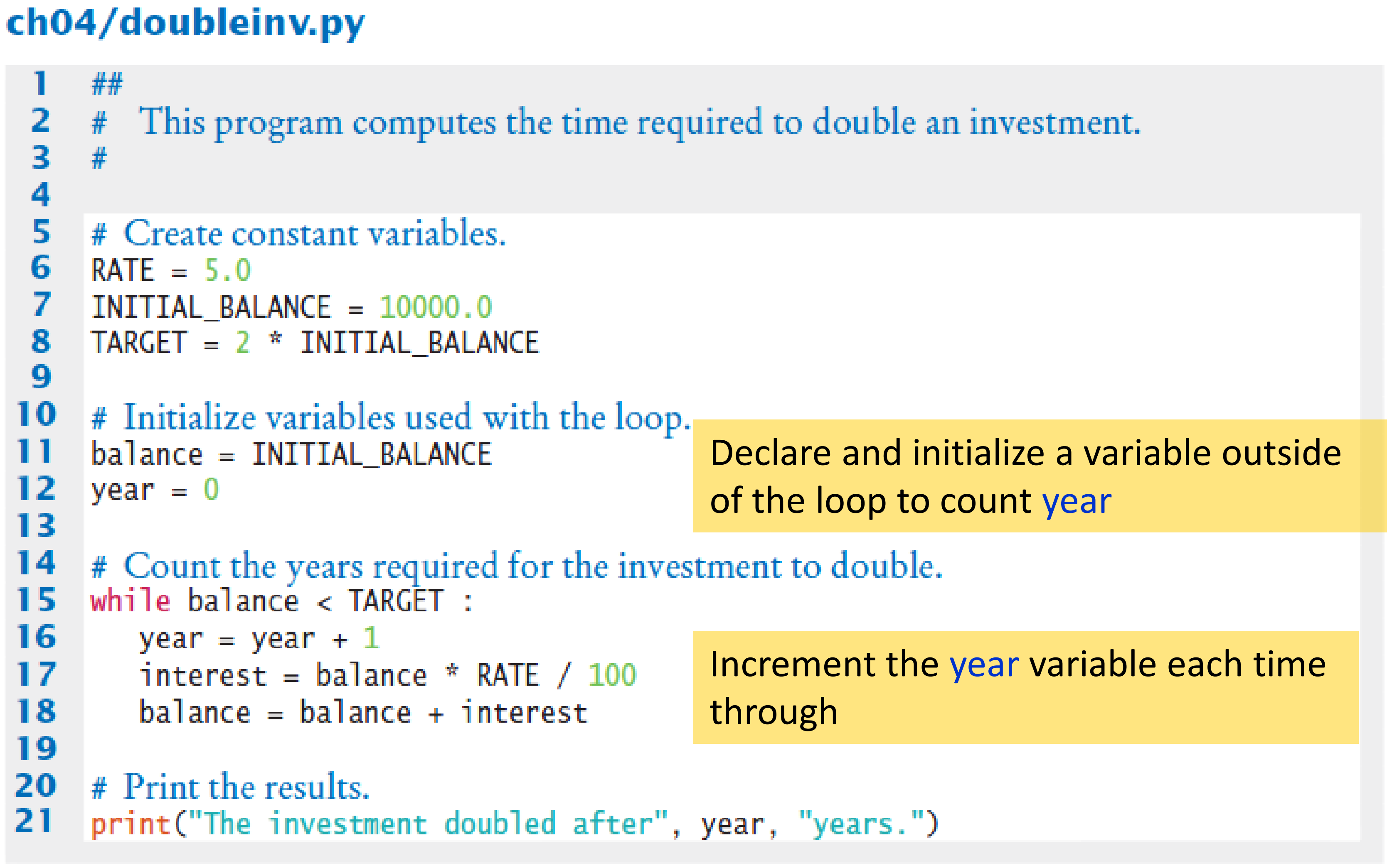


```
while balance < TARGET :
    year = year + 1
    interest = balance * RATE / 100
    balance = balance + interest
```



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

print(year)
```

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.")
```

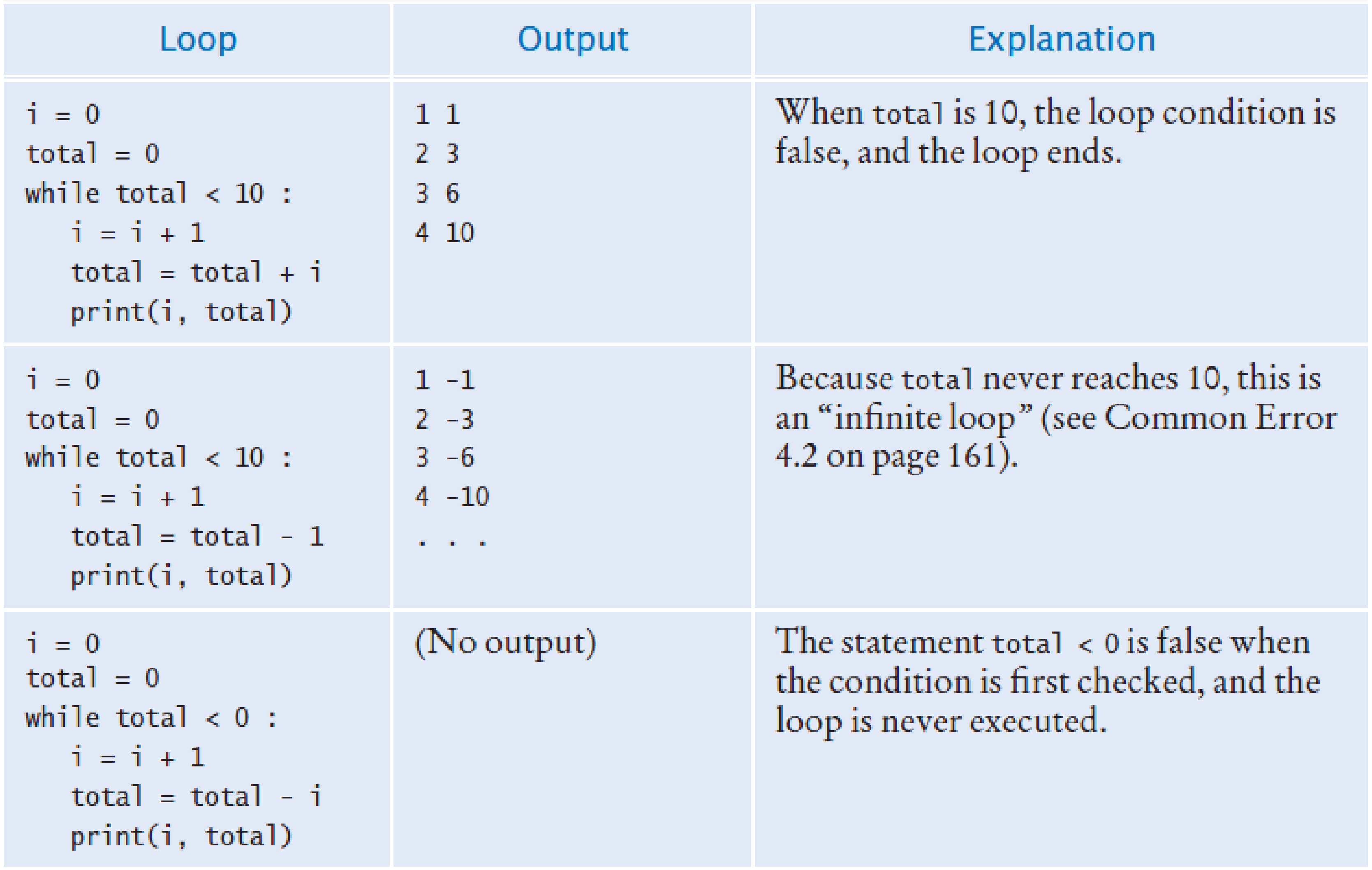
Declare and initialize a variable outside of the loop to count year

Increment the year variable each time through

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



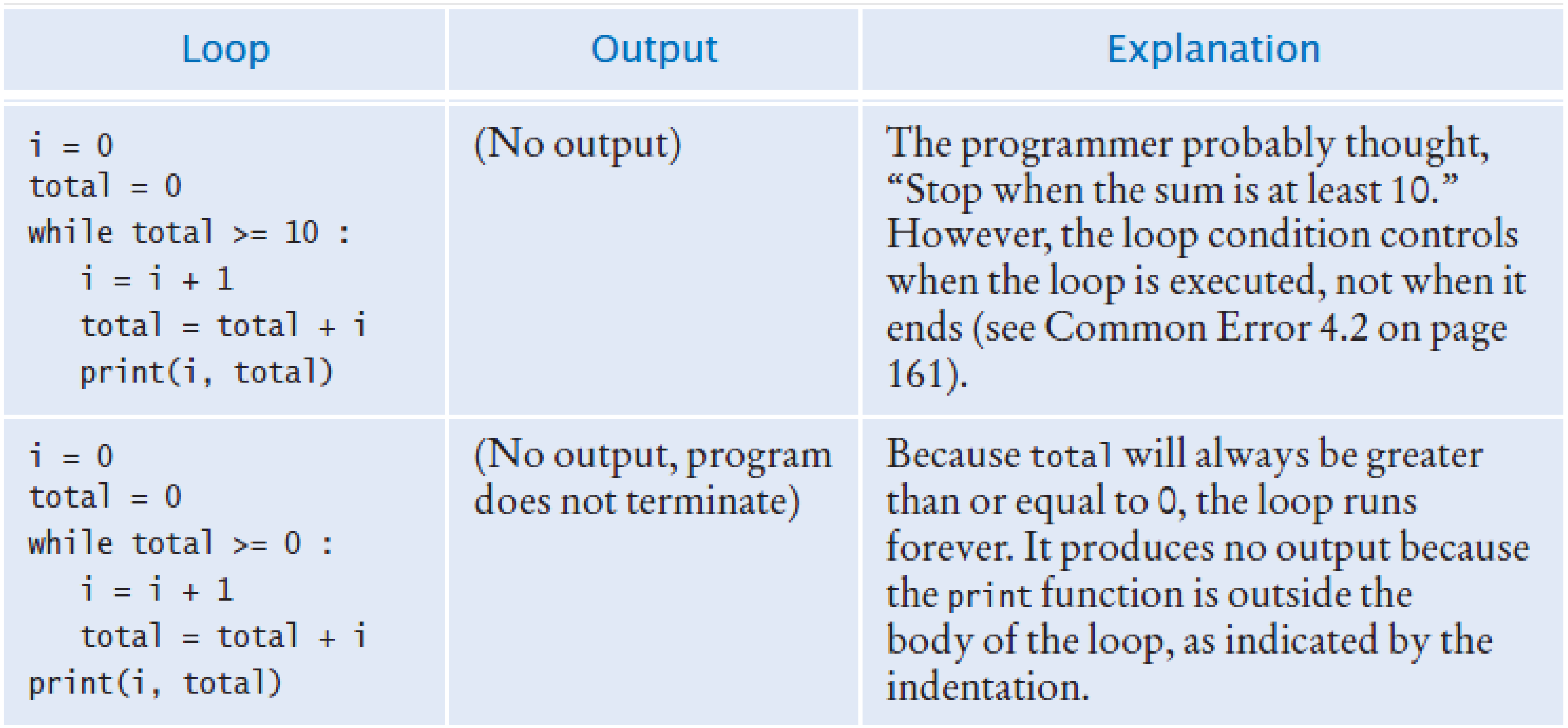
Loop	Output	Explanation

`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.
- If 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 I am done?
  - If you start at 0, use “<“ If you start at 1, use “<=“
  - 0, 1, 2, 3, 4 1, 2, 3, 4, 5

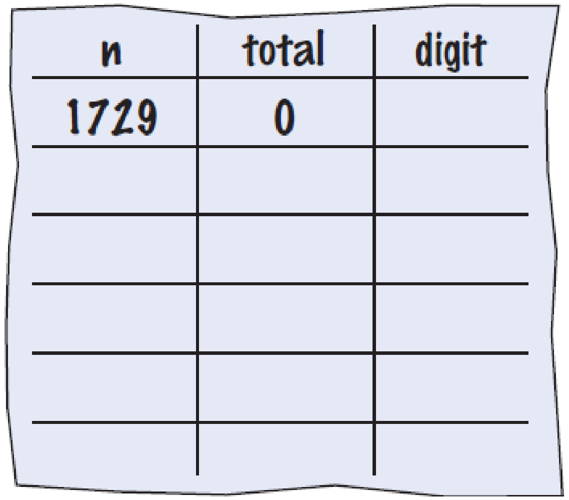
```
finger = 0
FINGERS = 5
while finger < FINGERS :
   # paint finger
   finger = finger + 1
```

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

Hand Tracing Loops

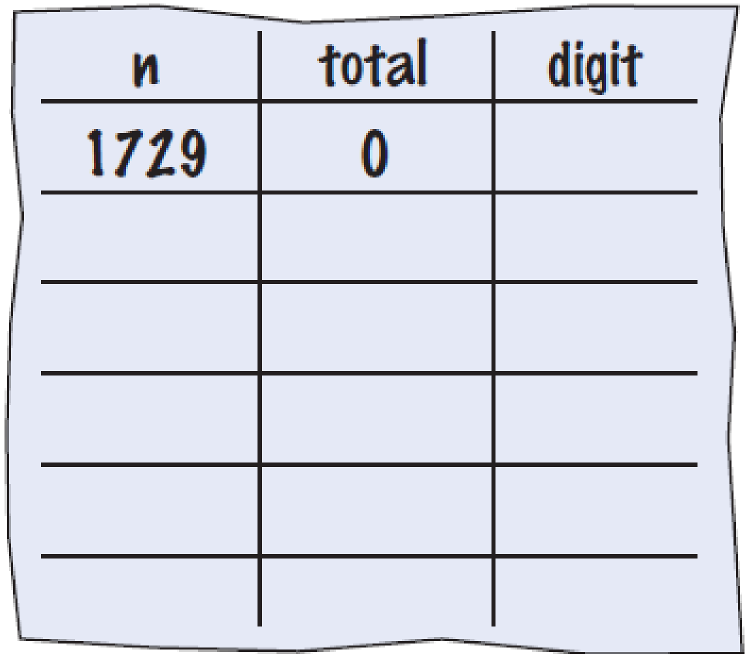
Hand-Tracing Loops

- 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	total	digit
1729	0	

Tracing Sum of Digits

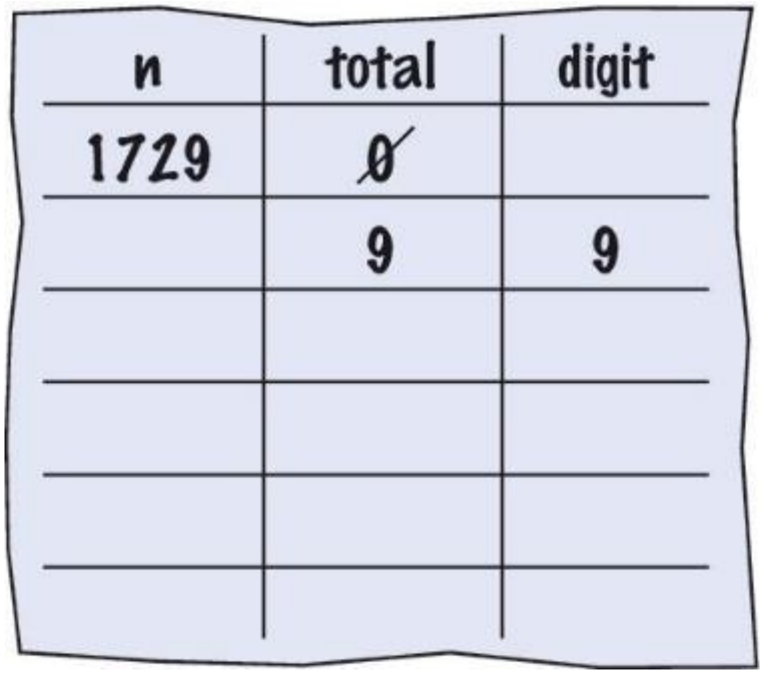


n	total	digit
1729	0	

```
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 line

Tracing Sum of Digits



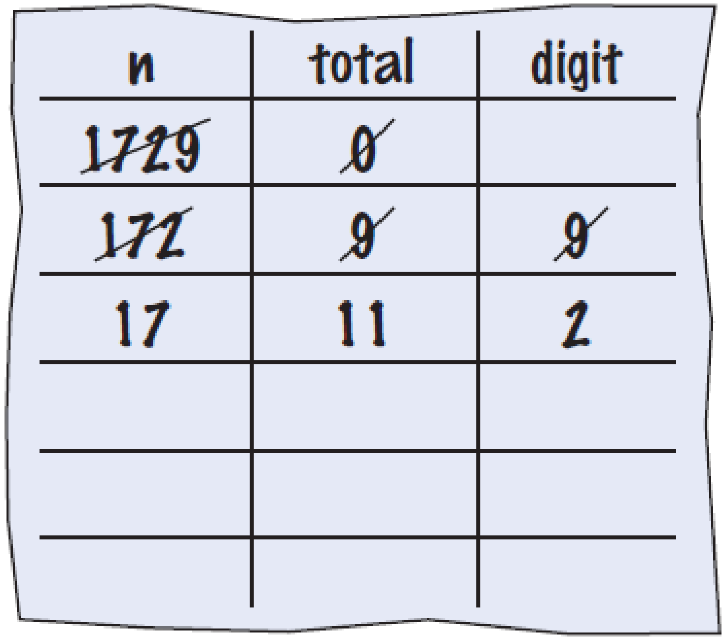
n	total	digit
1729	~~0~~	
	9	9

```
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



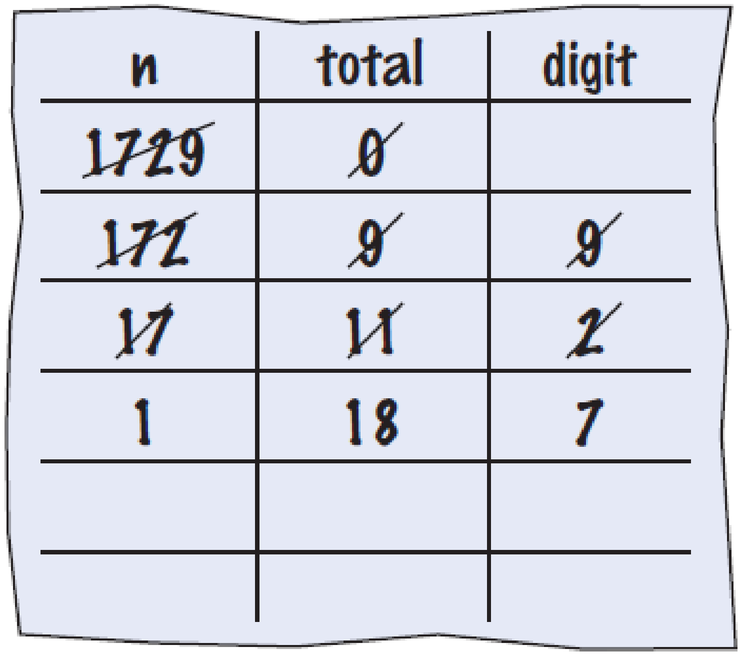
n	total	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
17	11	2

```
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

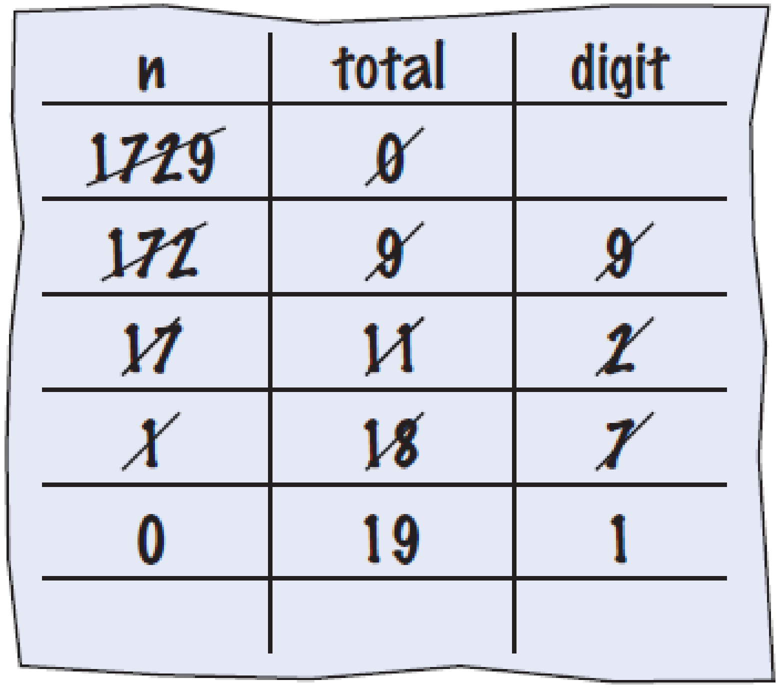


n	total	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
~~17~~	~~11~~	~~2~~
1	18	7

```
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)

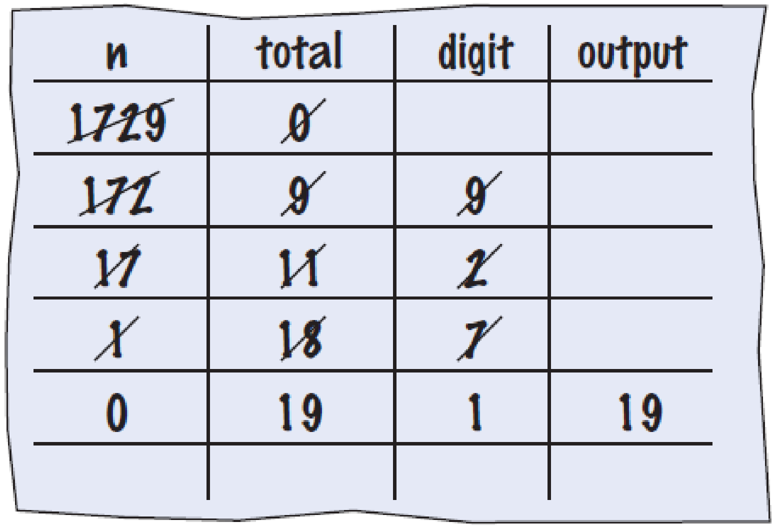


n	total	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
~~17~~	~~11~~	~~2~~
~~1~~	~~18~~	~~7~~
0	19	1

```
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 test
  - The condition is tested BEFORE the loop body
    - This is called pre-test
    - The condition often uses a counter variable
  - Something inside the loop should change one of the variables used in the test
- Watch out for infinite loops!

Sentinel Values

Processing Sentinel Values

- Sentinel values are often used:
  - When you don’t know how many items are in a list, use a ‘special’ character or value to signal the “last” item
  - For numeric input of positive numbers, it is common to use the value -1

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
```

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)

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

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

Outside the while loop: declare and initialize variables to use

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

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

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

Input new `salary` and compare to sentinel

```python
        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:
  - Sentinal.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.

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

- An alternative is to change the variable with a read before the loop.

```
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

Storyboards

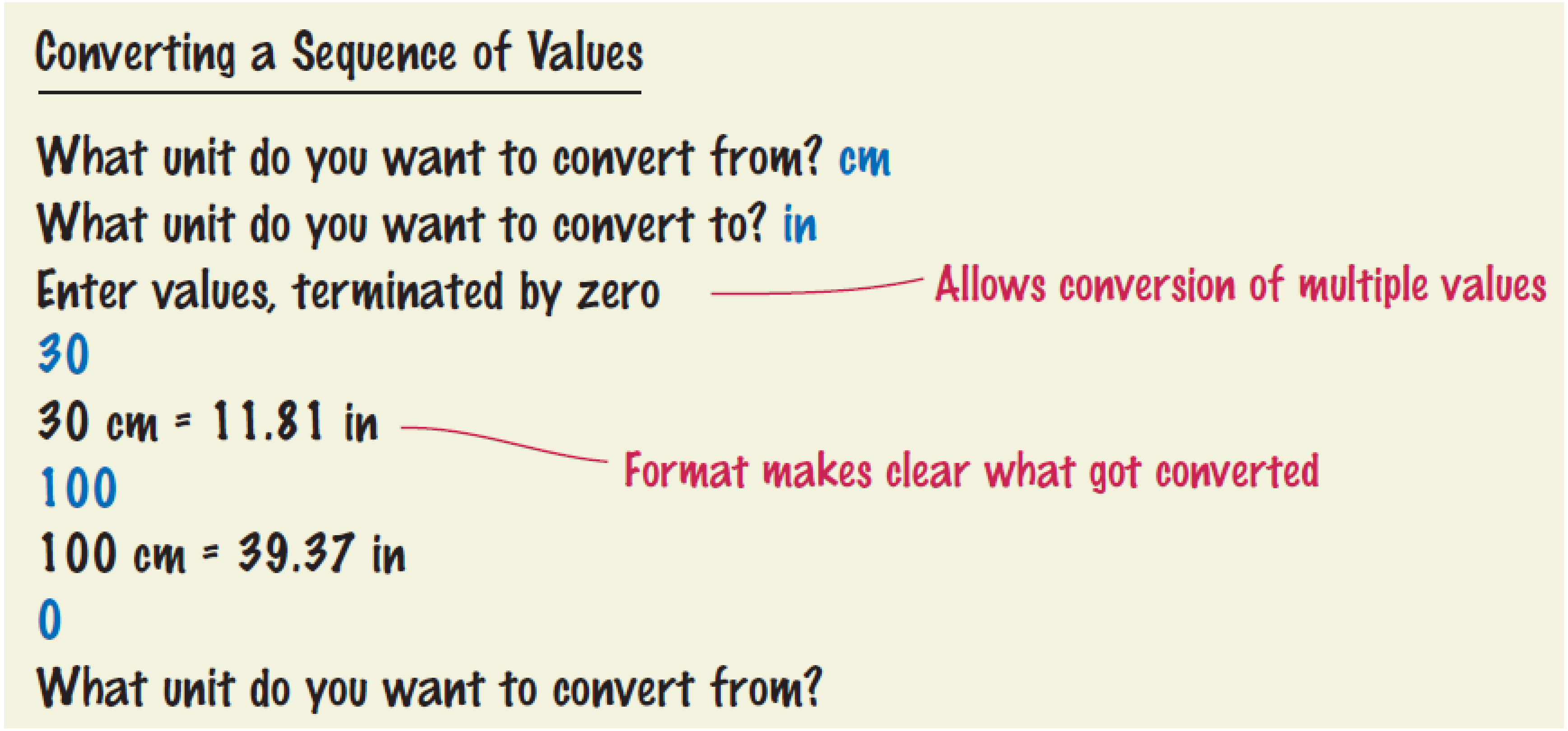
Storyboards

- One useful problem solving technique is the use of storyboards to model user interaction. It can help answer:
  - What information does the user provide, and in which order?
  - What information will your program display, and in which format?
  - What should happen when there is an error?
  - When does the program quit?

- ***A storyboard consists of annotated sketches for each step in an action sequence.***

Storyboard Example

- Goal: Converting a sequence of values
  - Will require a loop and some variables
  - Handle one conversion each time through the loop



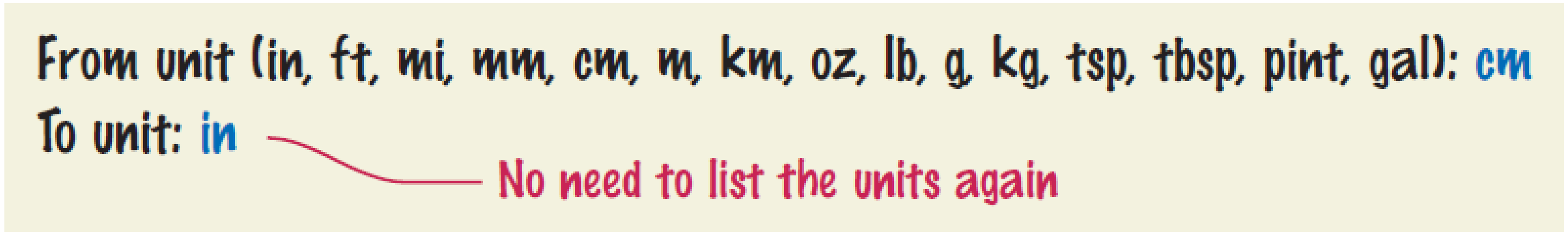
Converting a Sequence of Values

```
What unit do you want to convert from? cm
What unit do you want to convert to? in
Enter values, terminated by zero          Allows conversion of multiple values
30
30 cm = 11.81 in          Format makes clear what got converted
100
100 cm = 39.37 in
0
What unit do you want to convert from?
```

What Can Go Wrong?

Unknown unit types

- What is the user misspells centimeters and inches?
- What other conversions are available?
- Solution:
  - Show a list of the acceptable unit types

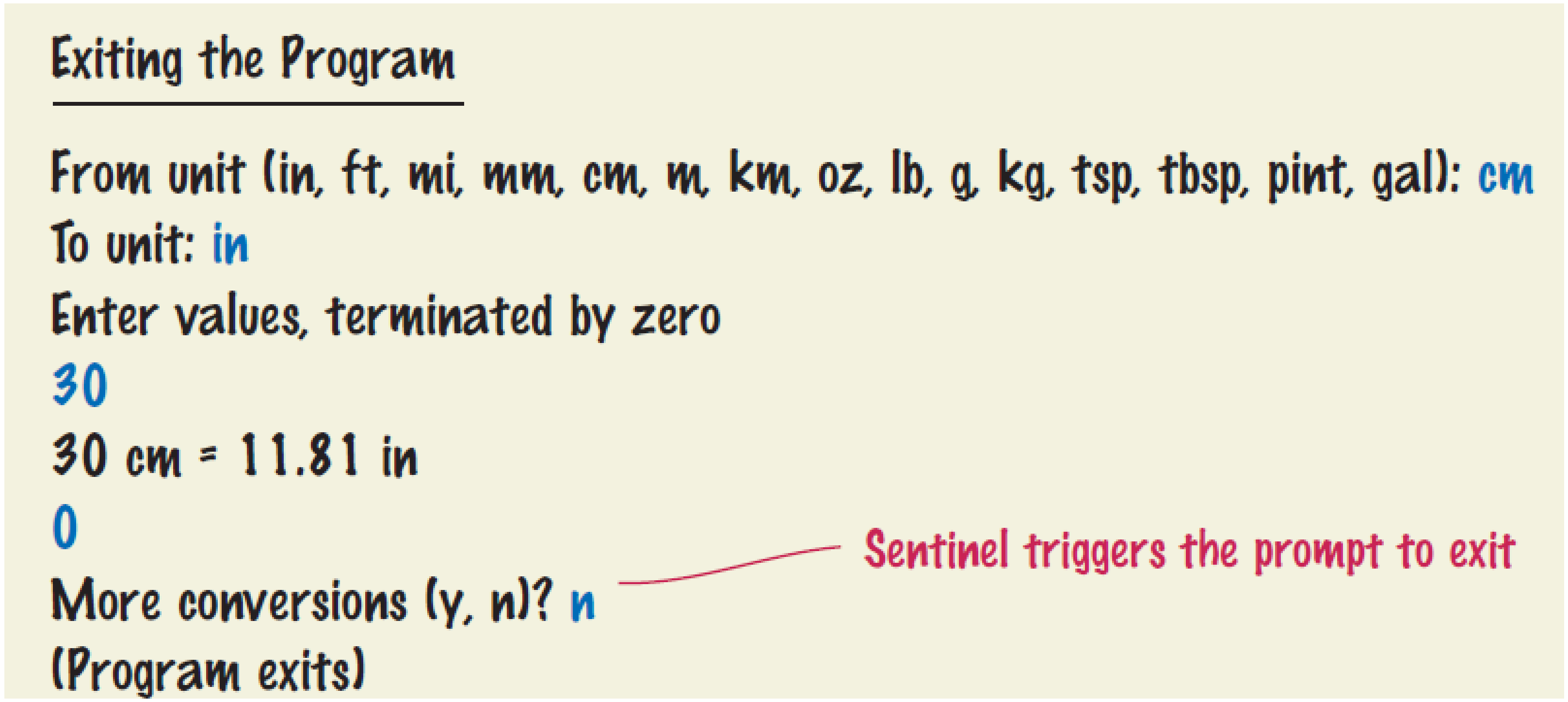


```
From unit (in, ft, mi, mm, cm, m, km, oz, lb, g, kg, tsp, tbsp, pint, gal): cm
To unit: in
```

No need to list the units again

What Else Can Go Wrong?

- How does the user quit the program?



Exiting the Program

```
From unit (in, ft, mi, mm, cm, m, km, oz, lb, g, kg, tsp, tbsp, pint, gal): cm
To unit: in
Enter values, terminated by zero
30
30 cm = 11.81 in
0
More conversions (y, n)? n
(Program exits)
```

Common Loop Algorithms

Common Loop Algorithms

1. Sum and Average Value
2. Counting Matches
3. Prompting until a Match Is Found
4. Maximum and Minimum
5. Comparing Adjacent Values

Average Example

Average of Values

- First total the values
- Initialize count to 0
  - Increment per input
- 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
```

Sum Example

- 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: ")
```

Counting Matches (e.g., Negative Numbers)

- Counting Matches
  - Initialize negatives to 0
  - Use a while loop
  - Add to negatives per match

```
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 use 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 (or smallest)
  - 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 (or smallest)
  - 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 input to previous variable
    - Get next value into input variable
    - Compare input to previous, and output if same

```
value = int(input("Enter a value: "))
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

The `for` Loop

- Uses of a **`for`** loop:
  - The **`for`** loop can be used to iterate over the contents of any **container**.
  - A **container** is is an object (Like a **string**) that contains or stores a collection of elements
  - A **string** is a container that stores the collection of characters in the string

An Example of a `for` Loop

- 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 stateName[0], stateName[1], and so on.

```
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

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
```

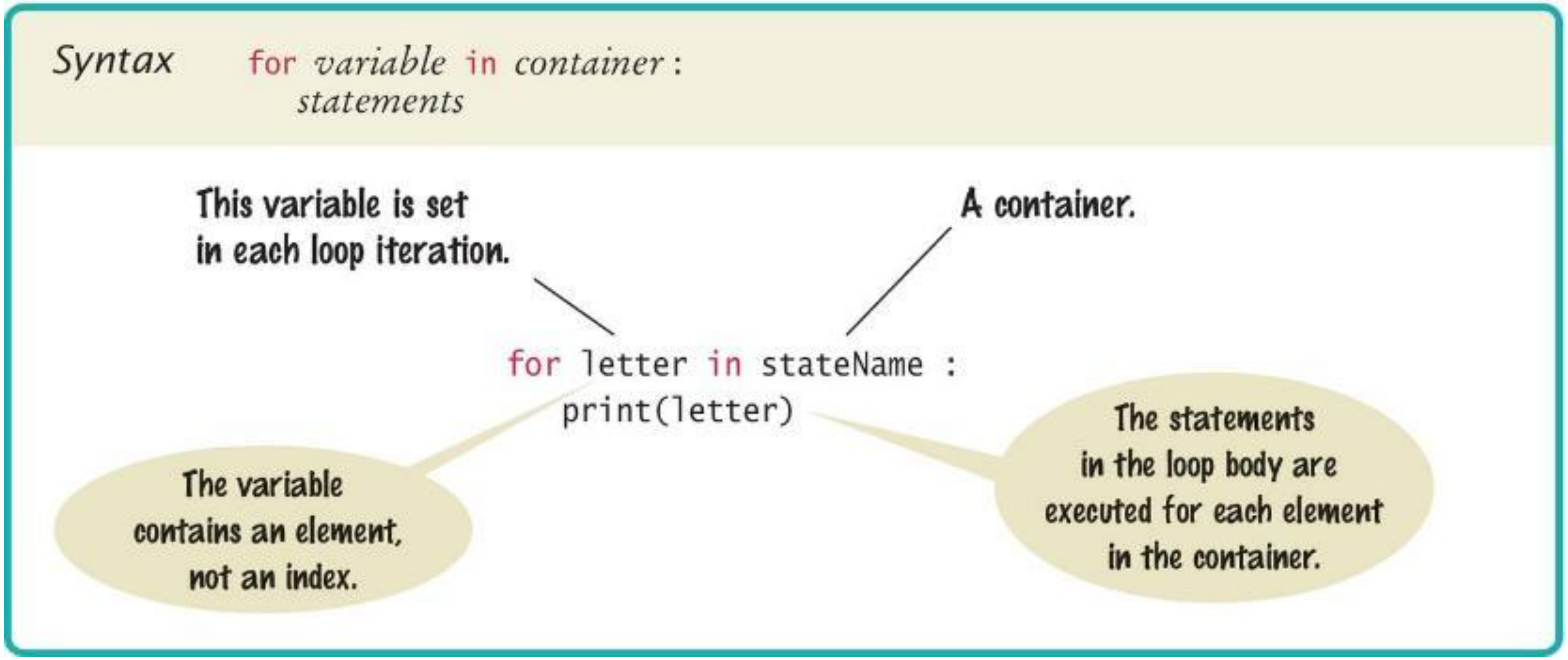
while version

```
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.



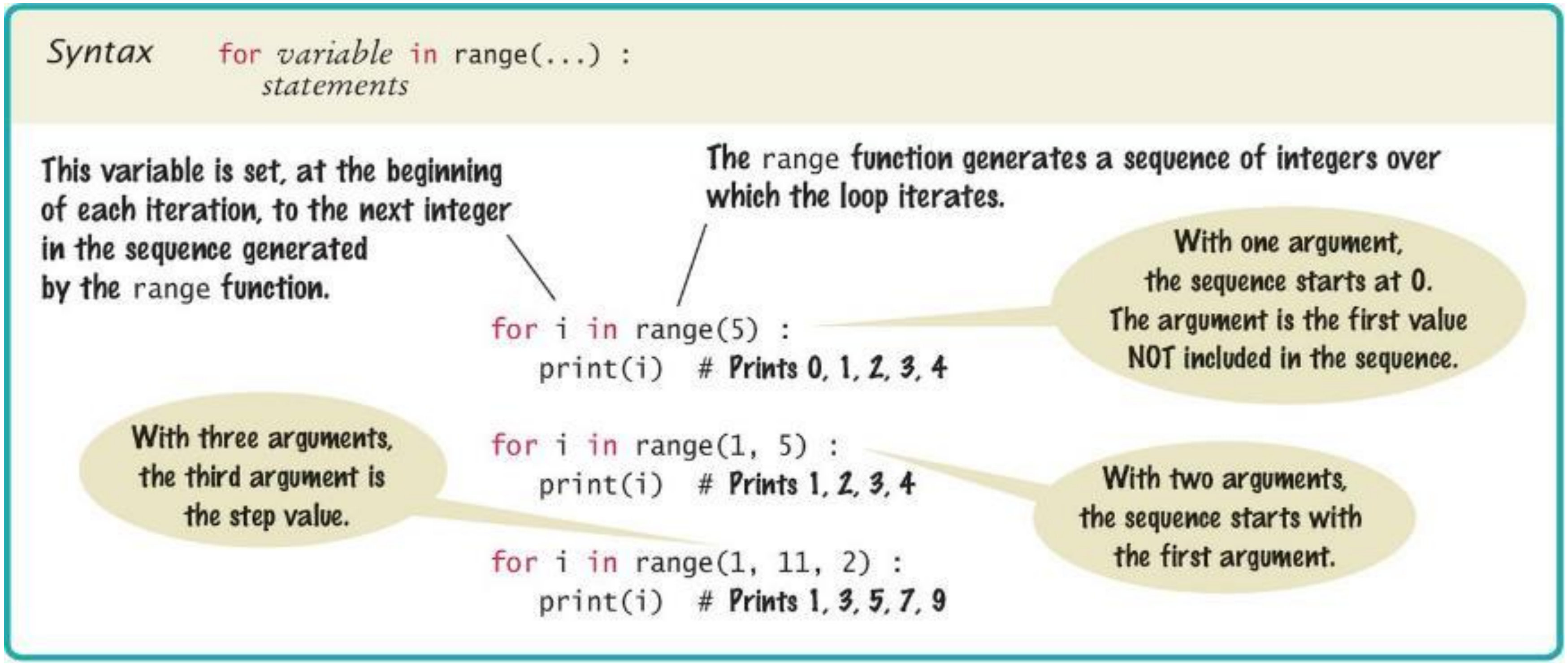
```
Syntax    for variable in container :
              statements
```

```
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
- We use the range function for generating a sequence of integers that less than the argument that can be used with the for loop



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

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

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

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

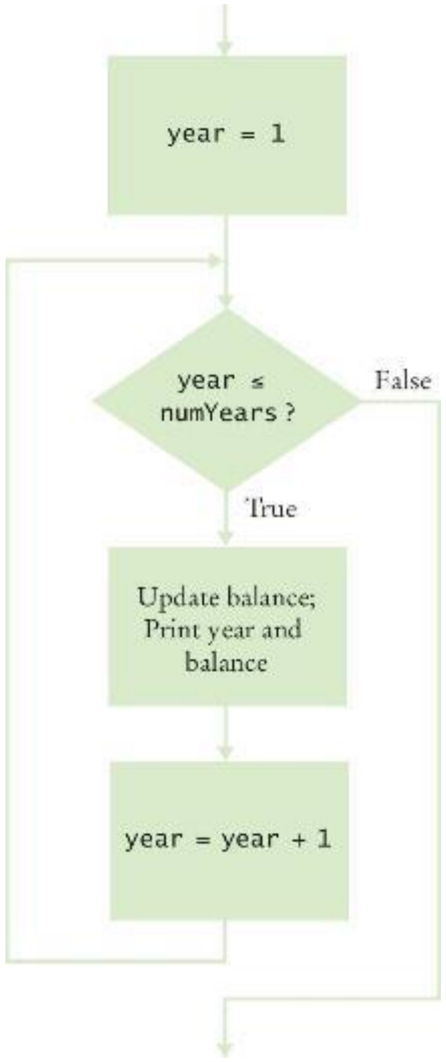
This variable is set, at the beginning of each iteration, to the next integer in the sequence generated by the range function.
The range function generates a sequence of integers over which the loop iterates.
With one argument, the sequence starts at 0. The argument is the first value NOT included in the sequence.
With three arguments, the third argument is the step value.
With two arguments, the sequence starts with the first argument.

Planning a **for** Loop

- 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!

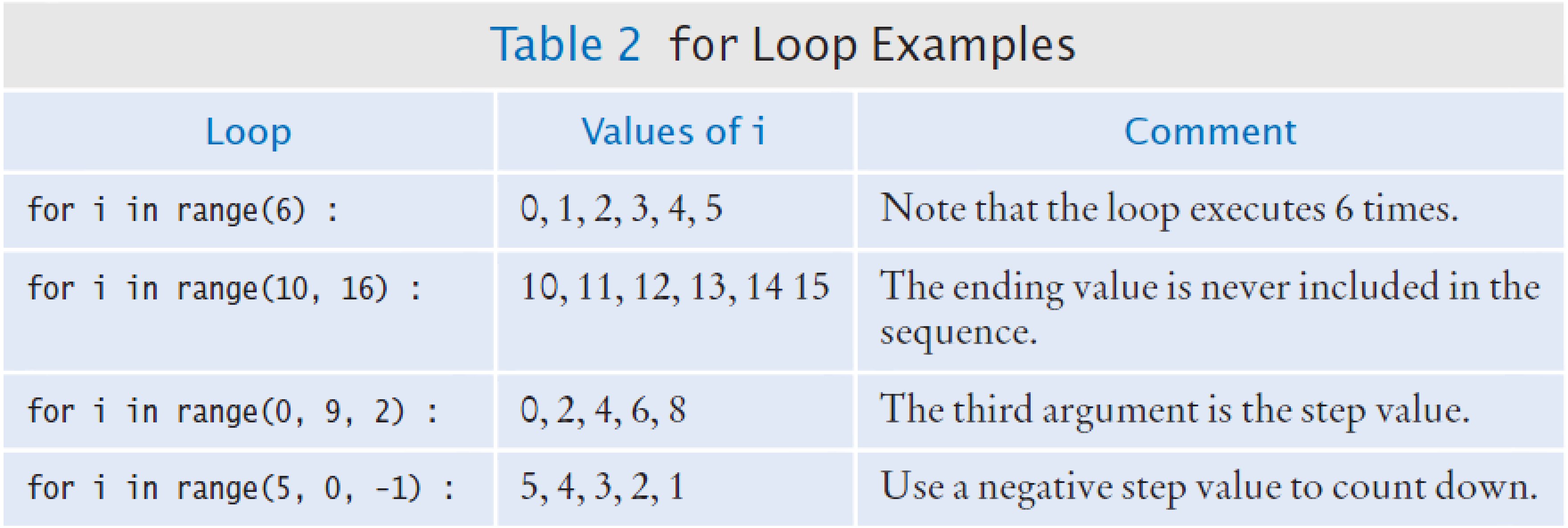
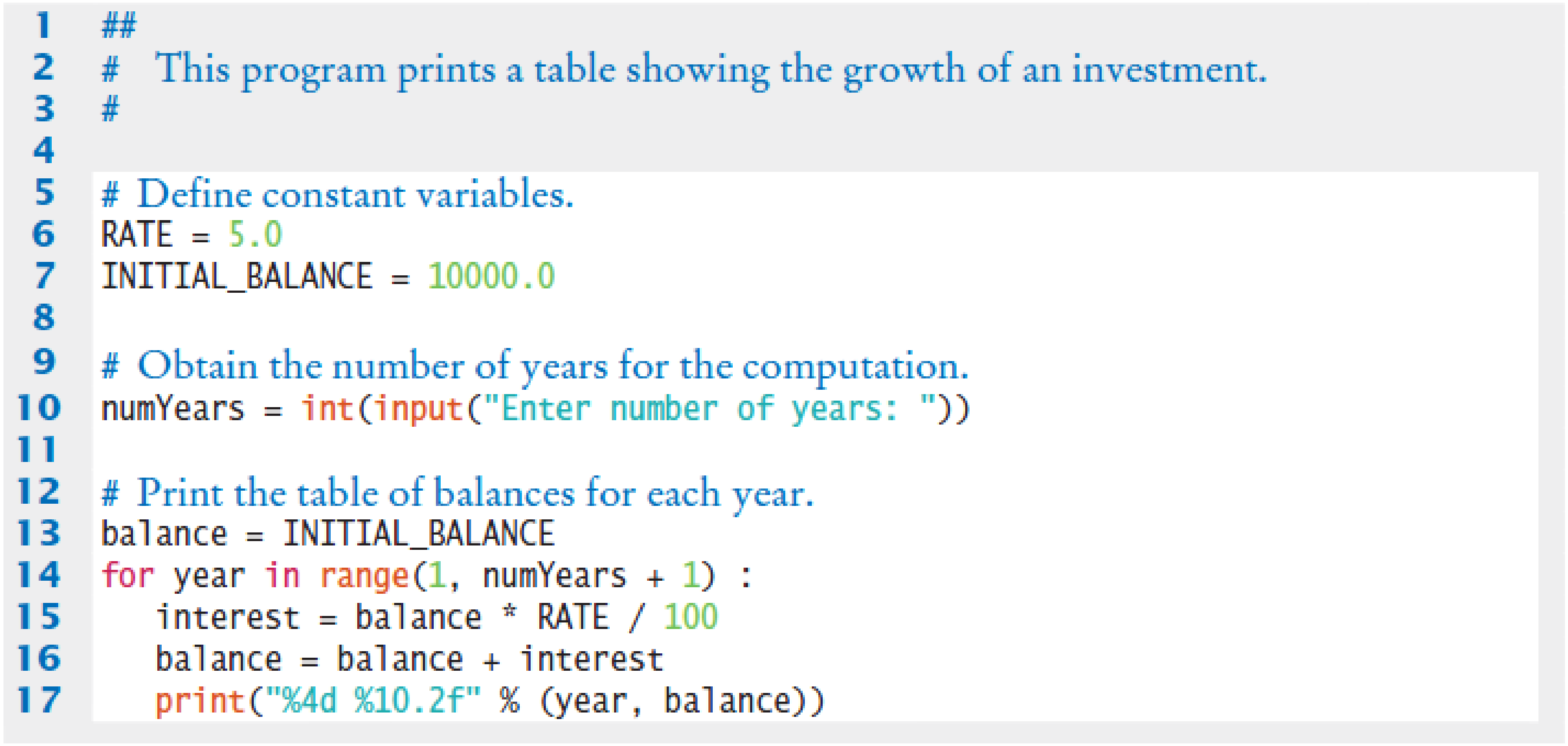


Table 2 for Loop Examples

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



```python
##
#   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.

```
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 Writing 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

A Special Form of the **`print`** Function

- Python provides a special form of the print function that 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 on a new line
- The output of the next **print** function starts on the same line

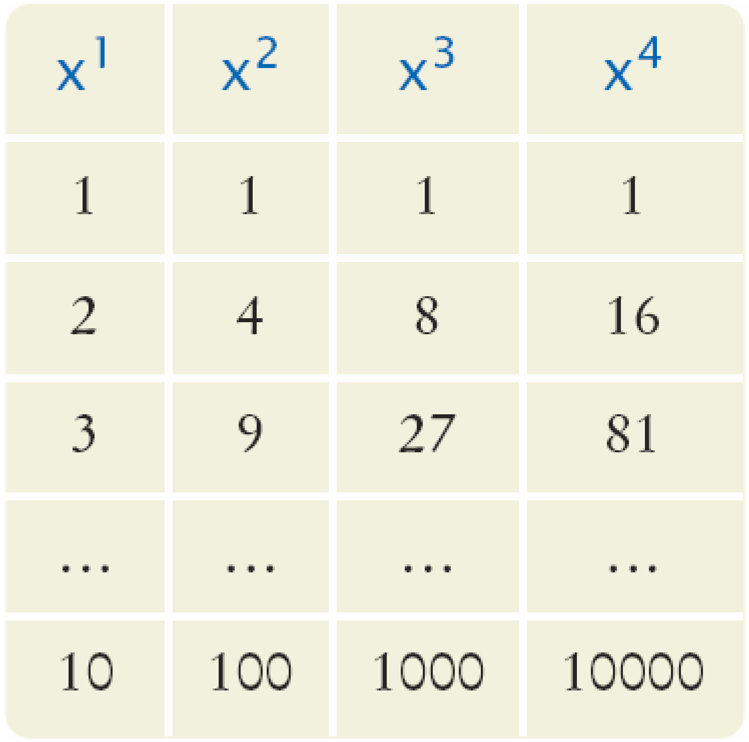
Nested Loops

Loops Inside of Loops

- In Chapter Three we learned how to nest **if** statements to allow us to make complex decisions
  - Remember that to nest the **if** statements we need 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
  - The outer loop iterates over all of the rows in the table
  - The inner loop processes the columns in the current row

Our Example Problem Statement

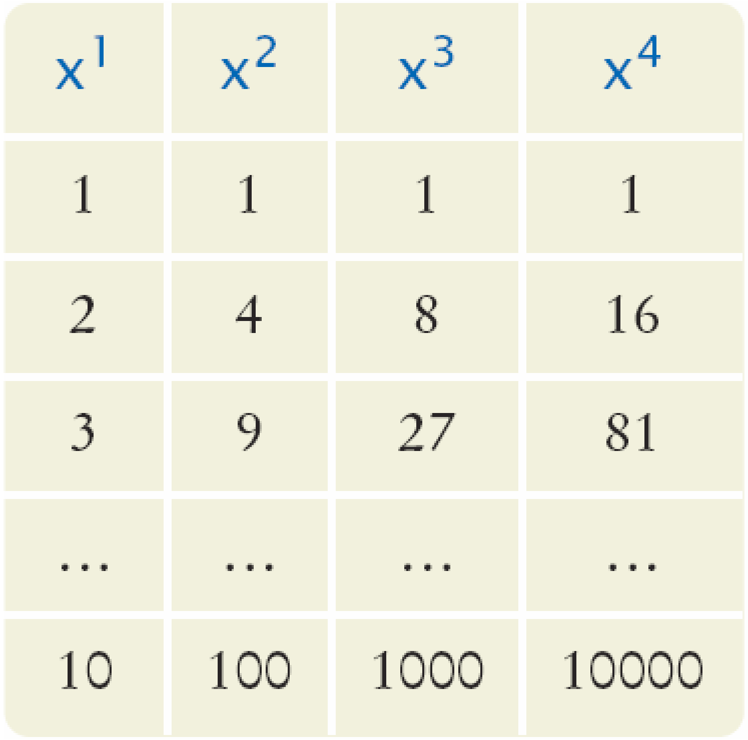
- Print a Table Header that contains x^1, x^2, x^3, and x^4
- Print a Table with four columns and ten rows that contain the powers of x^1, x^2, x^3, and x^4 for x = 1 to 10



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 preceding loop
  - The inner loop is *“nested”* inside the outer loop

Pseudocode to Print the Table

Print the table header:

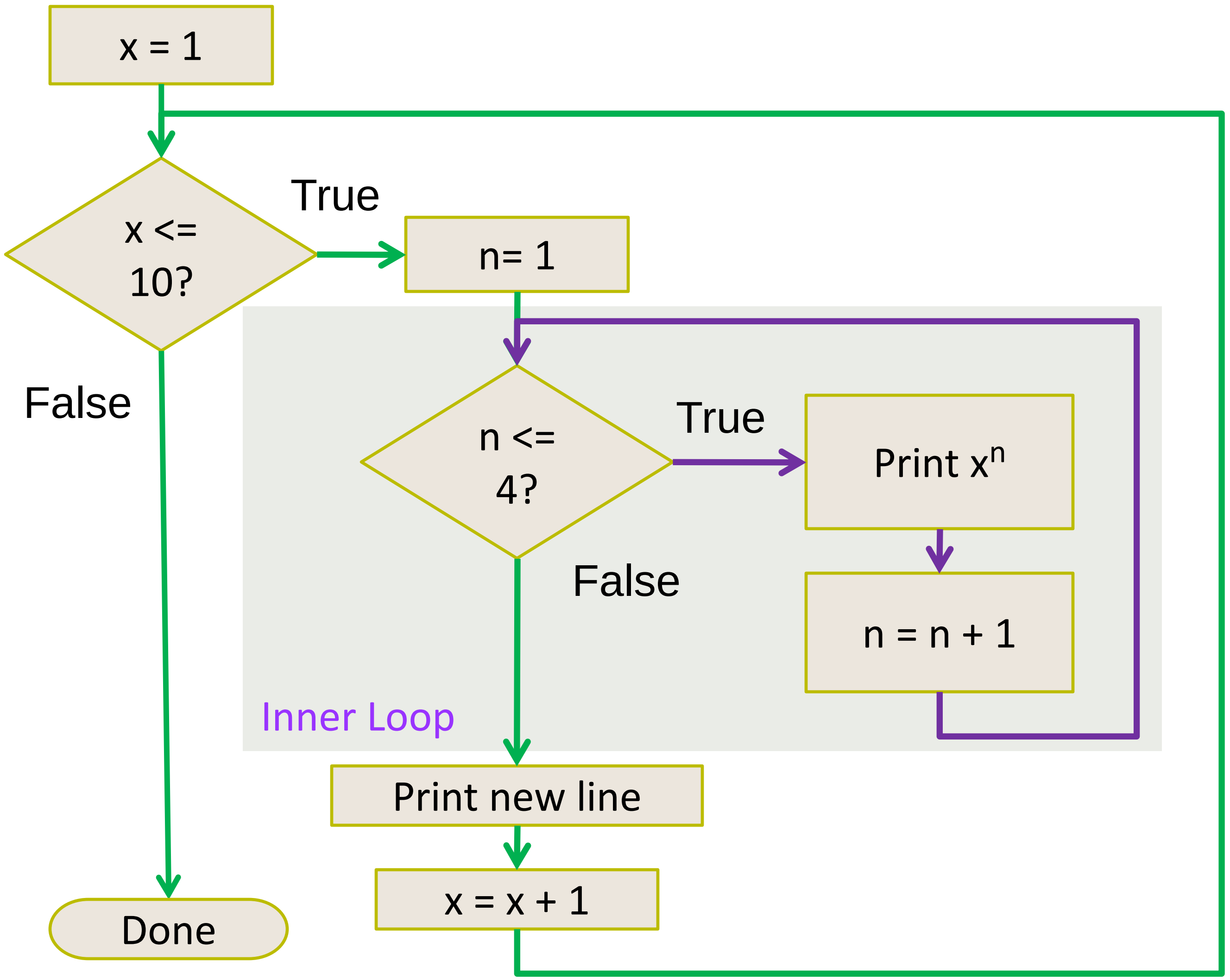
```
for x from 1 to 10
  for n from 1 to 4
    print $X^n$
  print a new line
```

n ➔

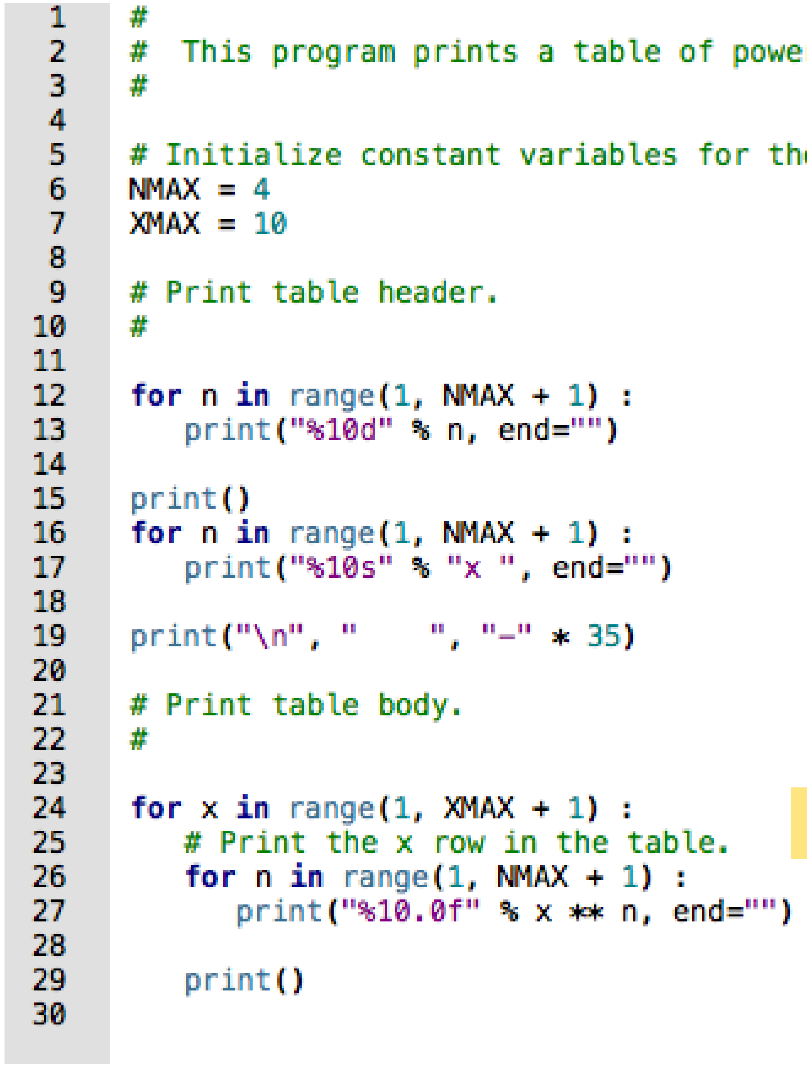
x ↓

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



Powertable.py



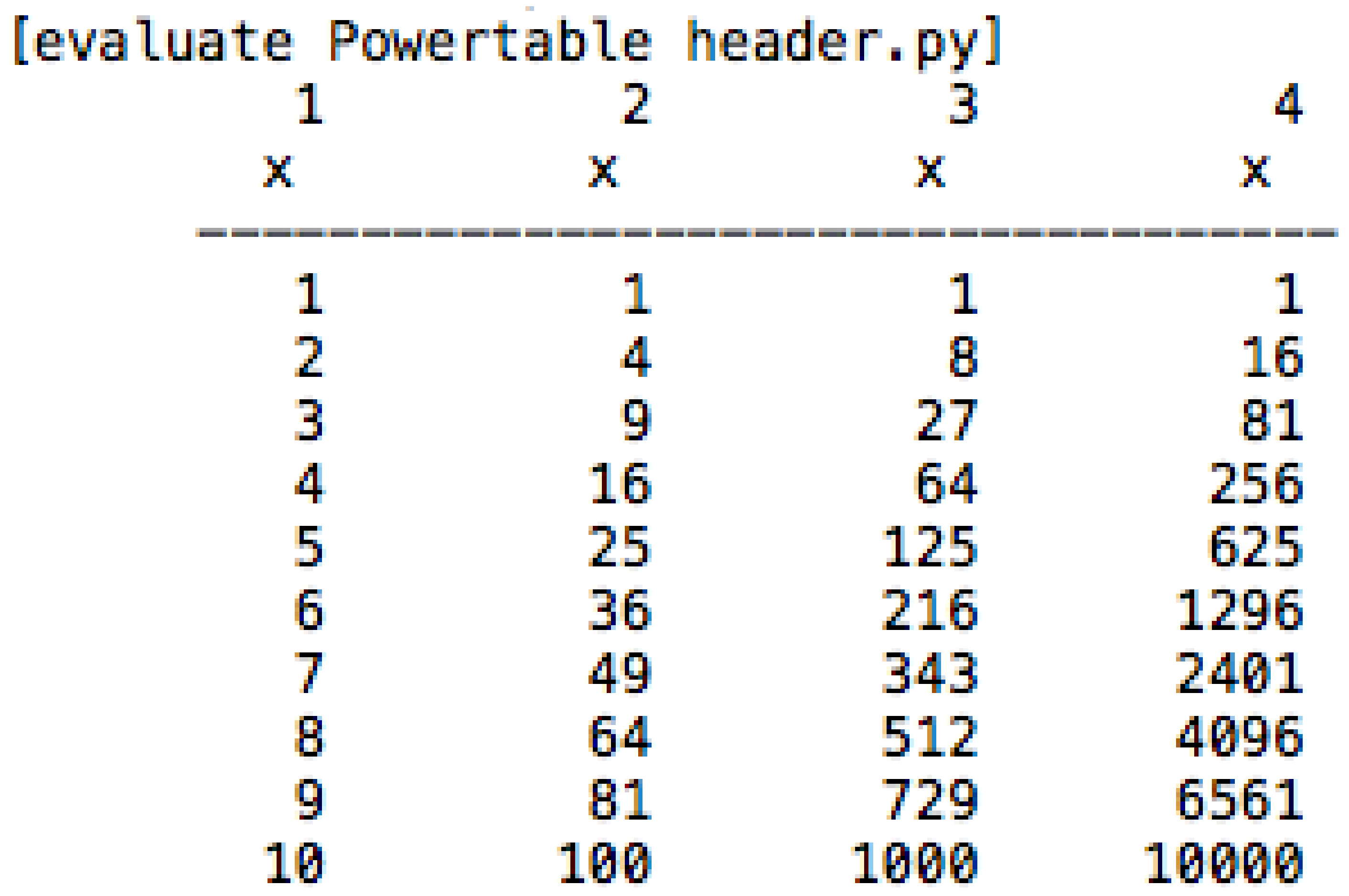
```python
#
#  This program prints a table of powers of x.
#

# 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
```

First 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

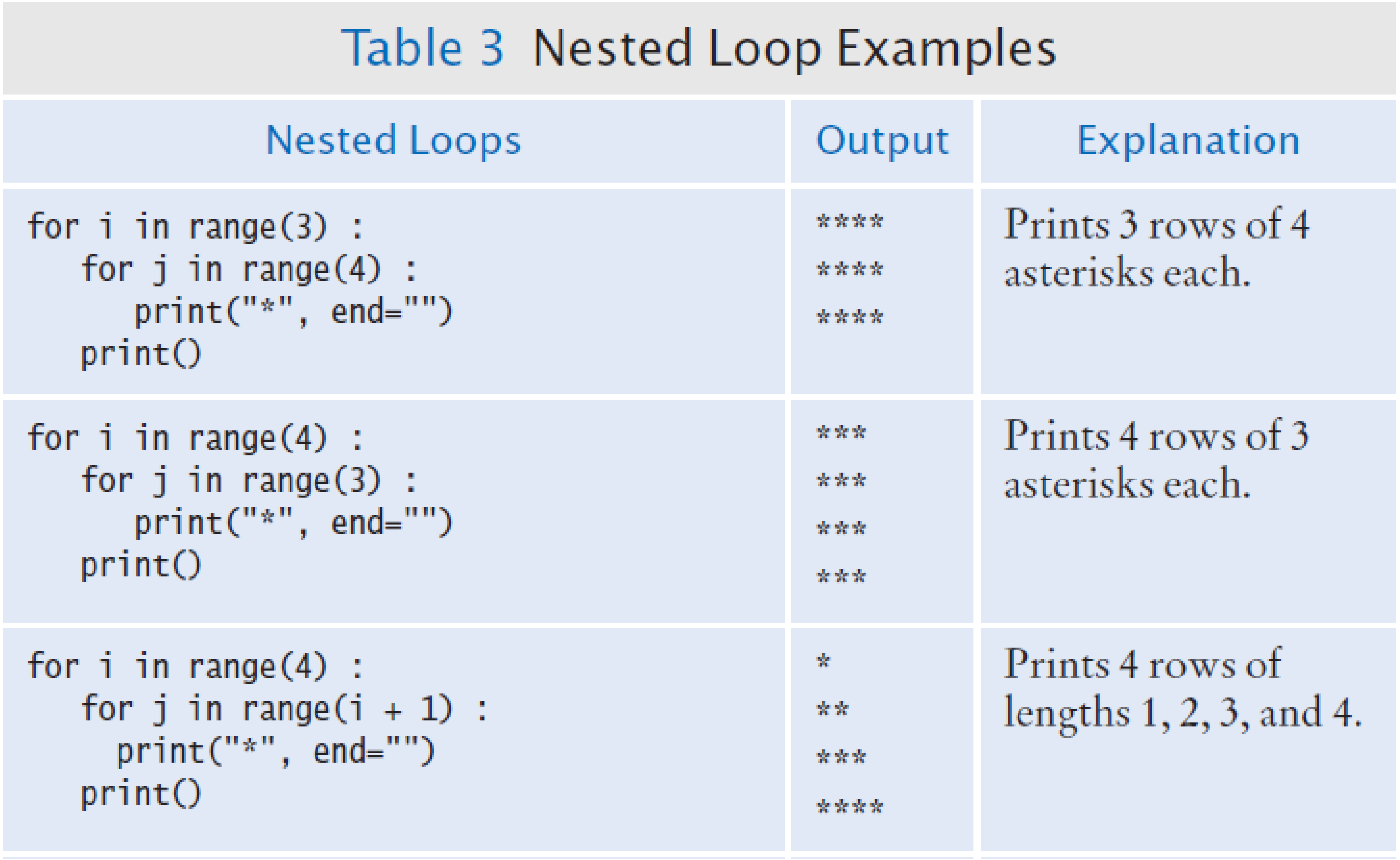


Table 3 Nested Loop Examples

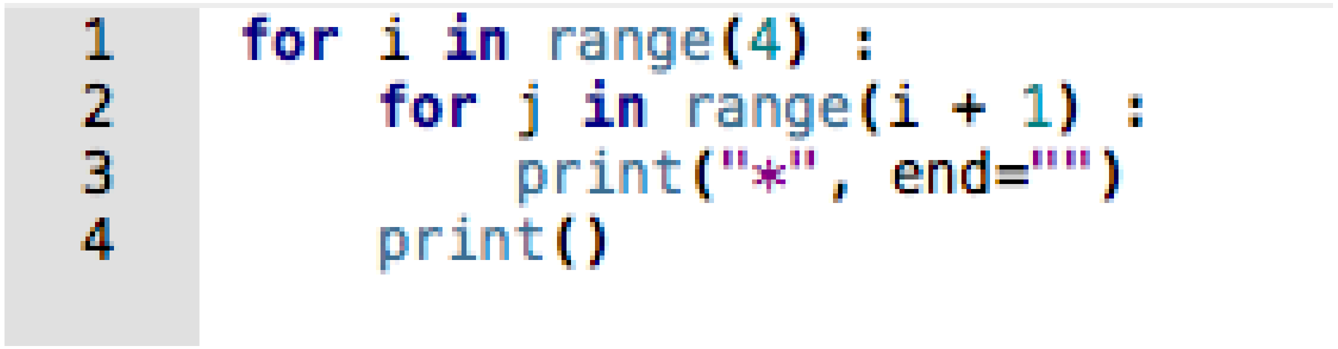
Nested Loops	Output	Explanation

`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.

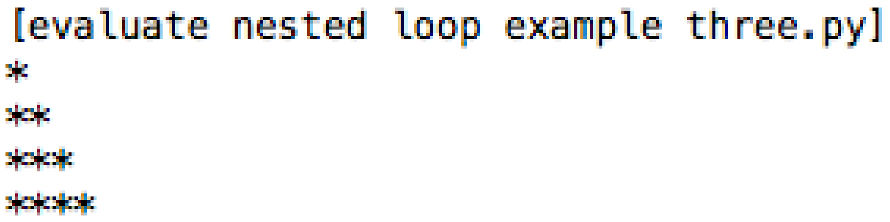
`for i in range(4) :`
`   for j in range(i + 1) :`
`     print("*", end="")`
`   print()`
	`*`
	`**`
	`***`
	`****`
		Prints 4 rows of lengths 1, 2, 3, and 4.

Hand Tracing the Loop



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

- i will have the values:
  - 0, 1, 2, 3 – So we will have four lines of stars



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

- 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

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

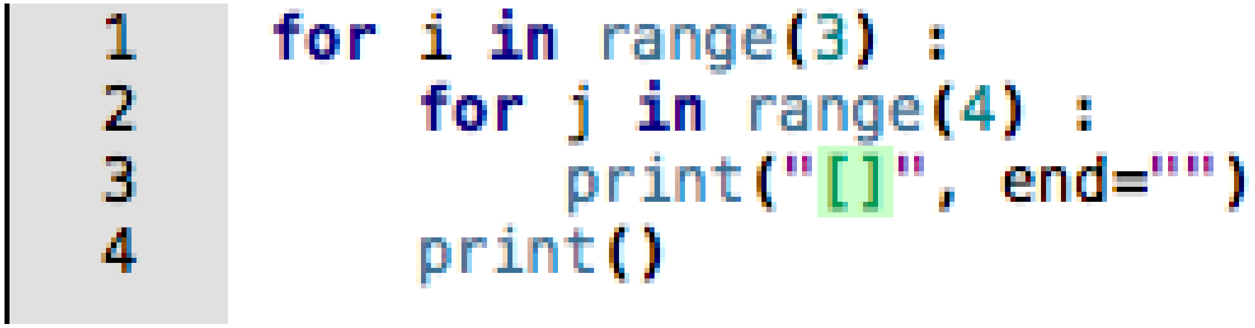
- Print the following pattern of brackets:

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

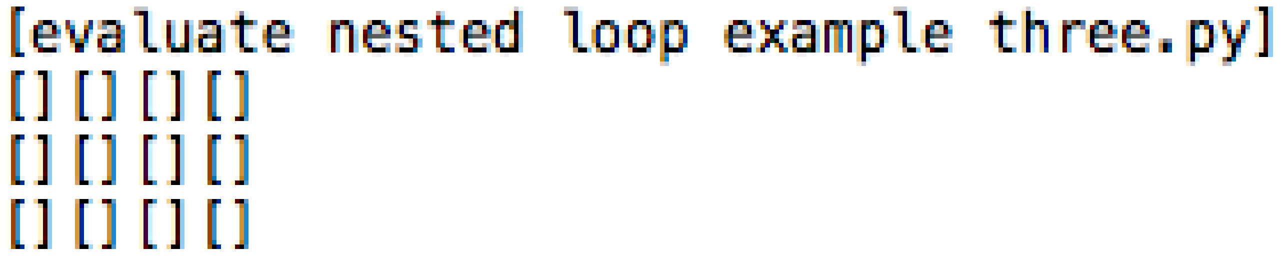
- The pattern consists of:
  - Three rows
  - Each row has four pairs of brackets
- What do we know?
  - We need two nested loops
    - The first loop (the outer loop) will print each of the three rows
    - The second loop (the inner loop) will print the four pairs of brackets

Pseudocode Code, Results

```
For i = 1 to 3
  For j = 1 to 4
    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]
[][][][]
[][][][]
[][][][]
```

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 student's grades

Step Two

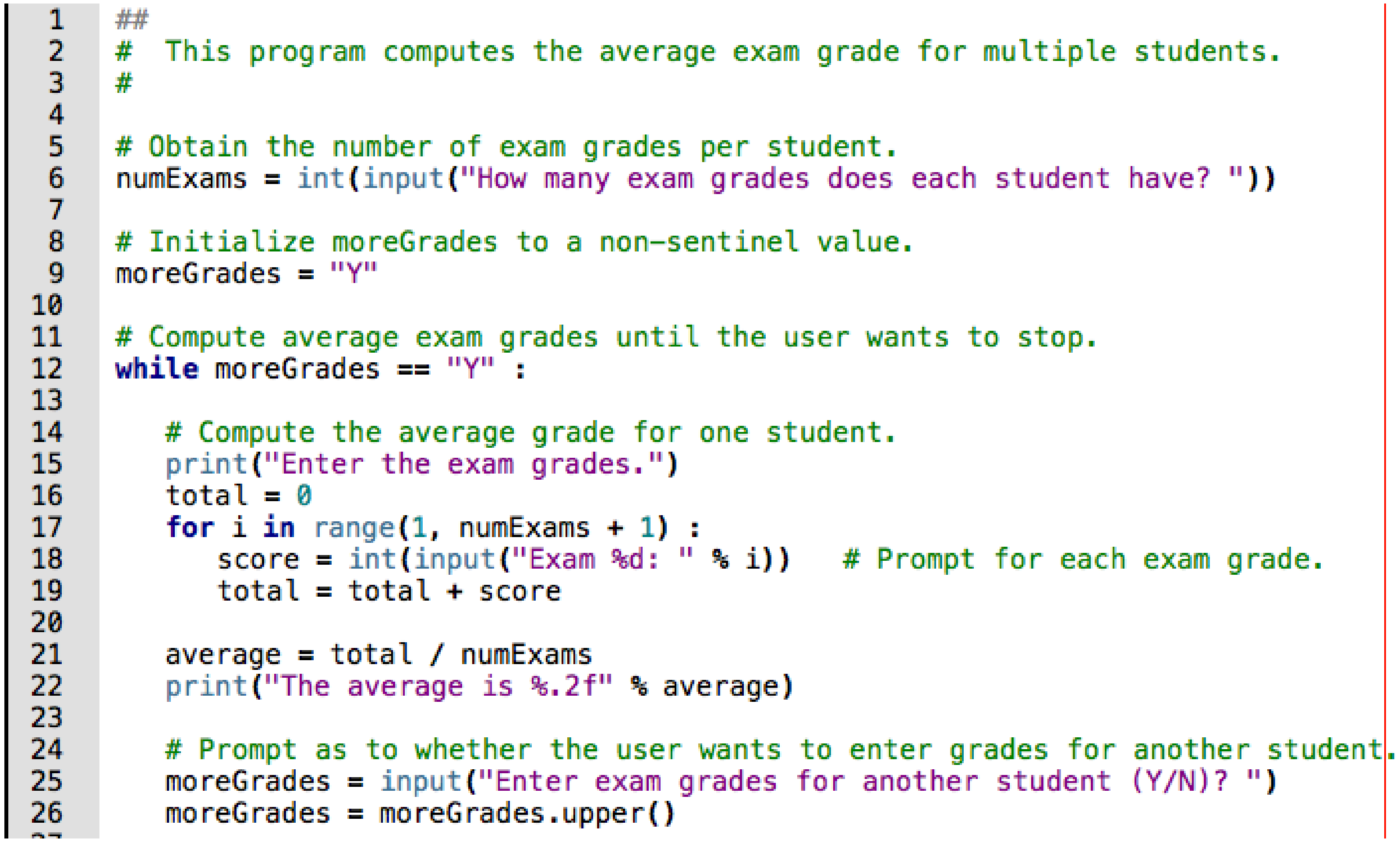
- Compute the grade for one student
- Set up the variables and loop
- We know how many grades to process, so we can use a count-controlled loop

```
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

Step Four: Translate to Python

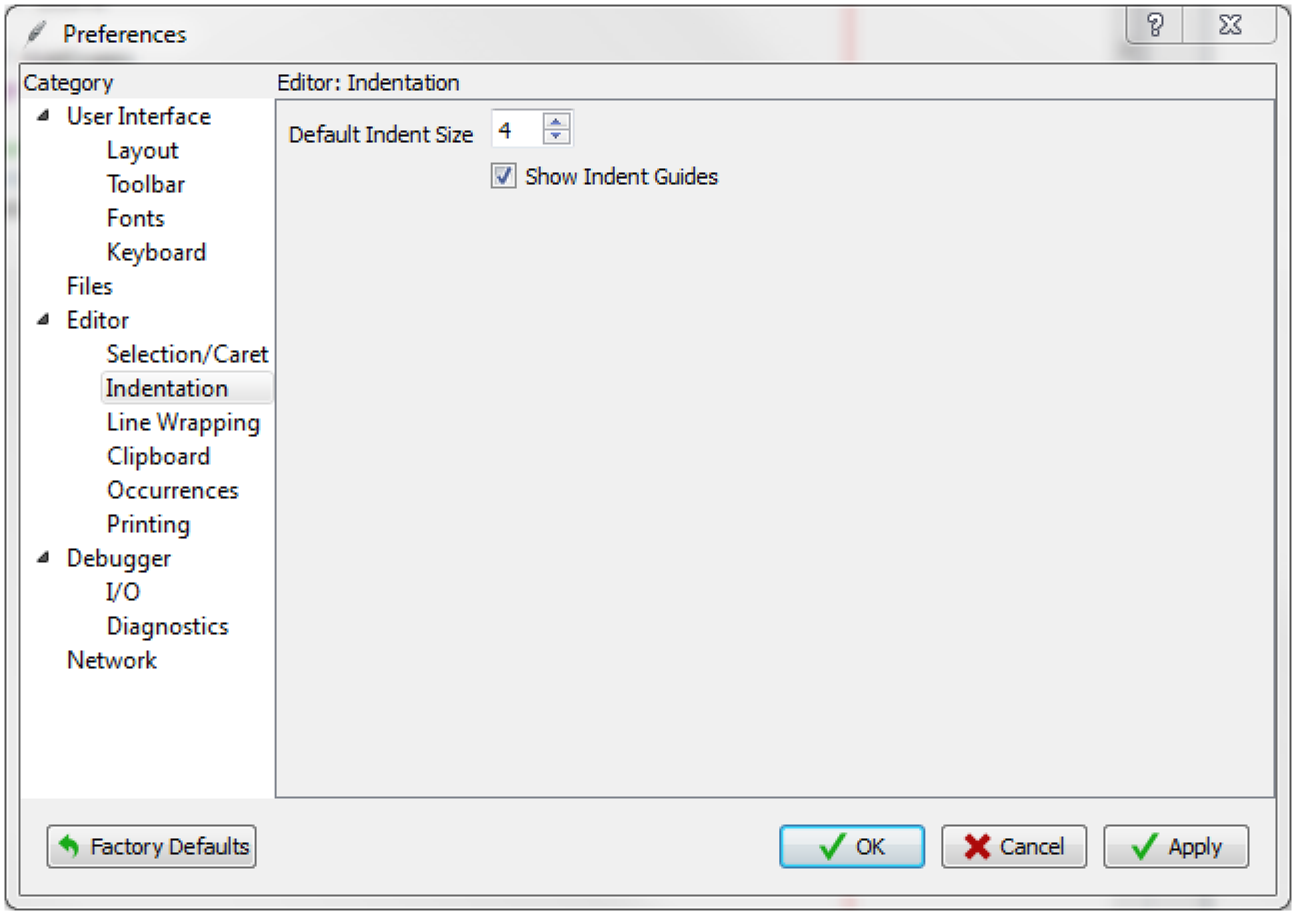


```python
##
#  This program computes the average exam grade for multiple students.
#

# 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
- In Wing you should see a line (the indent guide) connecting the **for** loop on line 17 down to the statement on line 21
  - The line is showing you the statements that are included in the **for** loop
- If you don’t see the indent guide:
  - Click on the edit tab
  - Select “Preferences…”
  - Under Editor, select Indention
  - Click the “Show Indent Guides” box
  - Click the Apply button
  - Click the Okay Button

Turning the Indent Guides On



Editor: Indentation

Default Indent Size: 4

[✓] Show Indent Guides

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.

Processing Strings

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 **char** 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 char in string :
   if char.isupper() :
      uppercase = uppercase + 1
```

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 **char** 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 in the string “aeiou”

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

Finding All Matches Example

- When you 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 test each character in the string and print the position of all uppercase characters
- We set the range to be the length of the string
  - We test each character
  - If it is uppercase we print I, its position in the string

```
sentence = input("Enter a sentence: ")
for i in range(len(sentence)) :
   if sentence[i].isupper() :
      print(i)
```

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 from the end of the string to 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 (###)###-####.

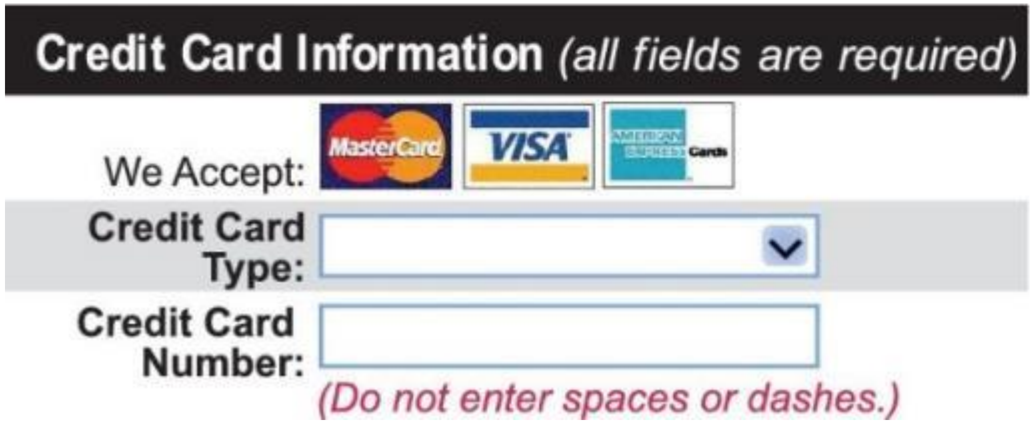
Validating a String (code)

- 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
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.
- 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

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

Application: Random Numbers and Simulations

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 <u>appear</u> 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

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

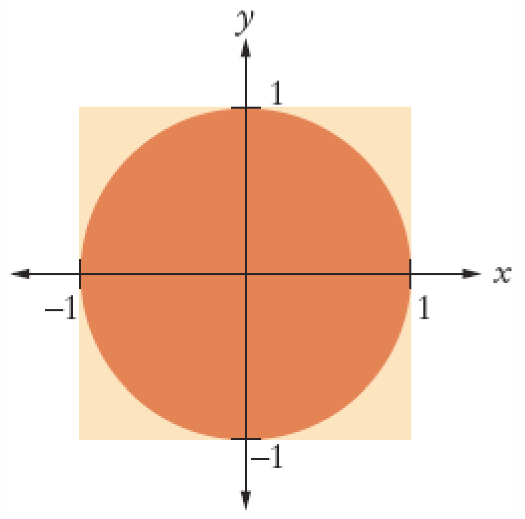
```python
##
#   This program simulates tosses of a pair of dice.
#

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

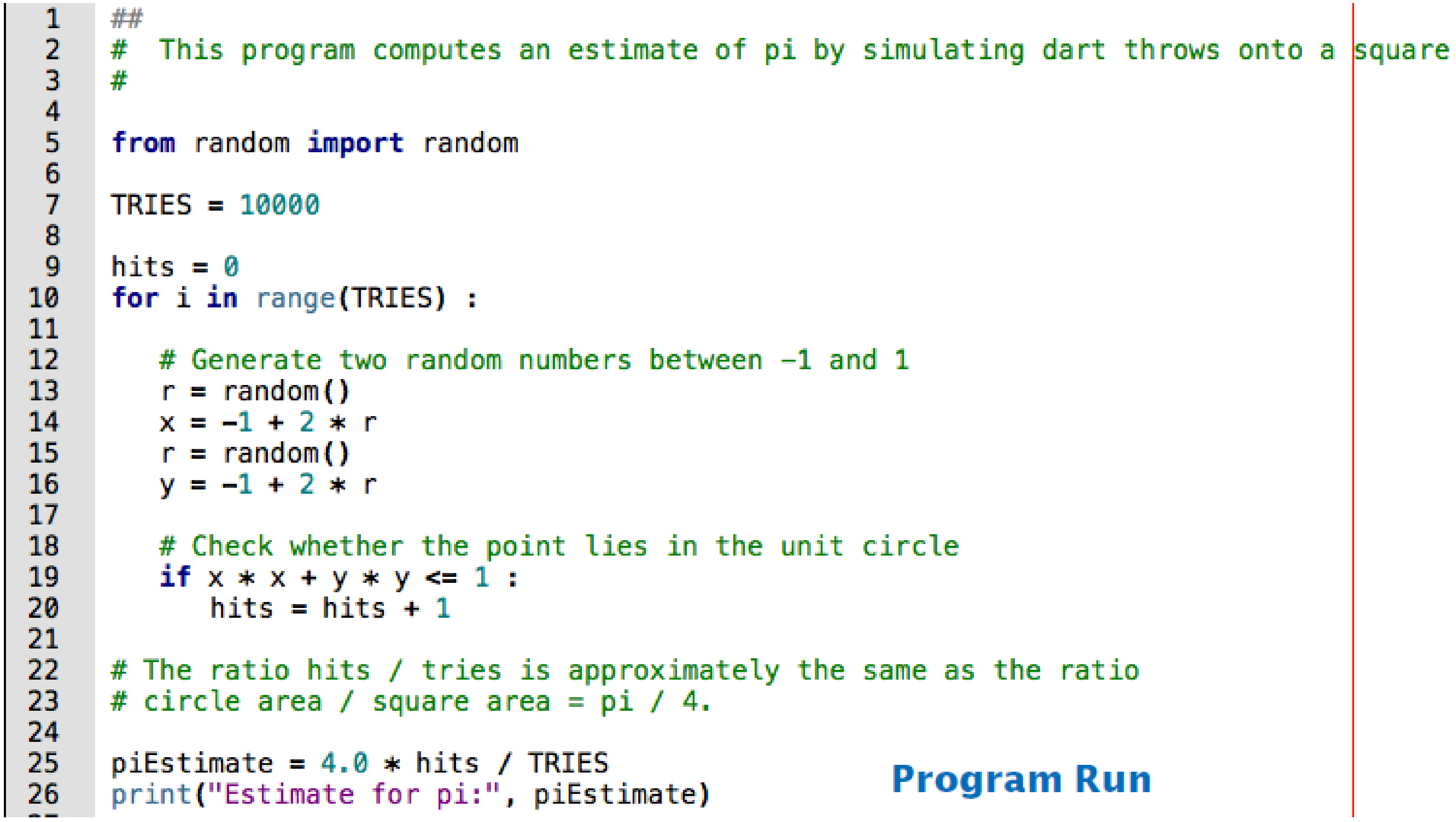
```
1 5
6 4
1 1
4 5
6 4
3 2
4 2
3 5
5 2
4 5
```

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
  - Hits are inside circle
  - Tries are total number of tries
  - Ratio is 4 x Hits / Tries

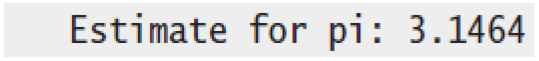


Monte Carlo Example



```
##
#  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
```

Graphics: Digital Image Processing

Manipulating Images

- Digital image processing is the use of algorithms to manipulate digital images
- It is used in:
  - Digital photography
  - Data compression
  - Computer graphics
  - Computer vision
  - Robotics
- We'll learn how to manipulate images with the `ezgraphics` package

Representing Images

- A digital image is composed of pixels arranged in a grid of rows and columns
  - Computer images appear “smooth” because very small points on the screen (very close together) are used to reproduce the individual pixels
- Pixels store data representing a color from the visual spectrum
  - The discrete RGB color model is the most used model
  - The three individual colors are specified by the amount of red, green, and blue light needed to produce a given color
  - The values are given as integers between 0 (no light present) and 255 (maximum light present)

Filtering an Image

- Filtering an image modifies the color component values of each pixel in some way

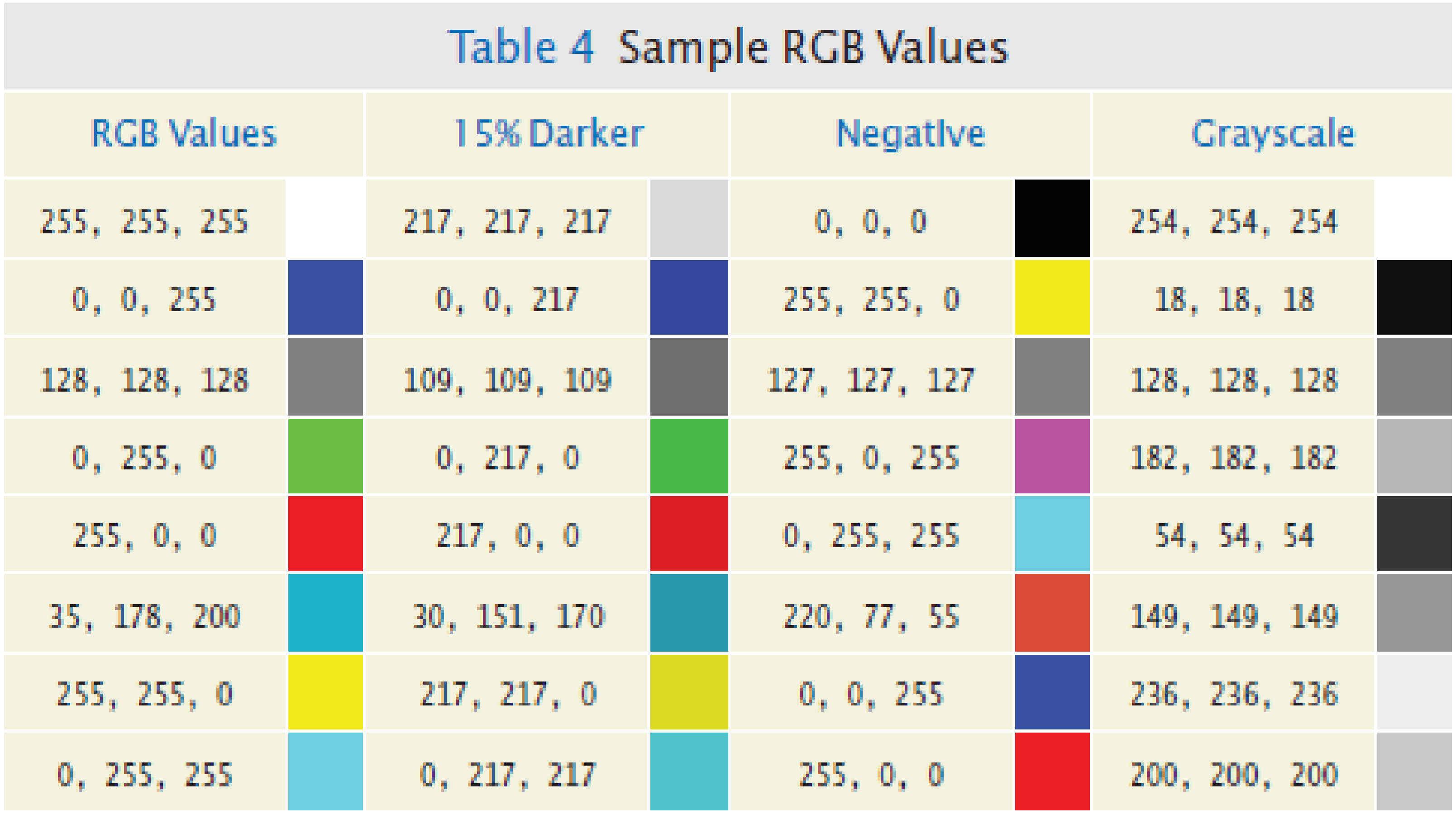


Table 4 Sample RGB Values

RGB Values		15% Darker		Negative		Grayscale	
255, 255, 255	⬜	217, 217, 217	▨	0, 0, 0	⬛	254, 254, 254	⬜
0, 0, 255	🟦	0, 0, 217	🟦	255, 255, 0	🟨	18, 18, 18	⬛
128, 128, 128	▨	109, 109, 109	▨	127, 127, 127	▨	128, 128, 128	▨
0, 255, 0	🟩	0, 217, 0	🟩	255, 0, 255	🟪	182, 182, 182	▨
255, 0, 0	🟥	217, 0, 0	🟥	0, 255, 255	🟦	54, 54, 54	⬛
35, 178, 200	🟦	30, 151, 170	🟦	220, 77, 55	🟧	149, 149, 149	▨
255, 255, 0	🟨	217, 217, 0	🟨	0, 0, 255	🟦	236, 236, 236	⬜
0, 255, 255	🟦	0, 217, 217	🟦	255, 0, 0	🟥	200, 200, 200	▨

Processing an Image

- We start by loading the image into our program
  - In ezgraphics an image is stored in an instance of the `GraphicsImage` class

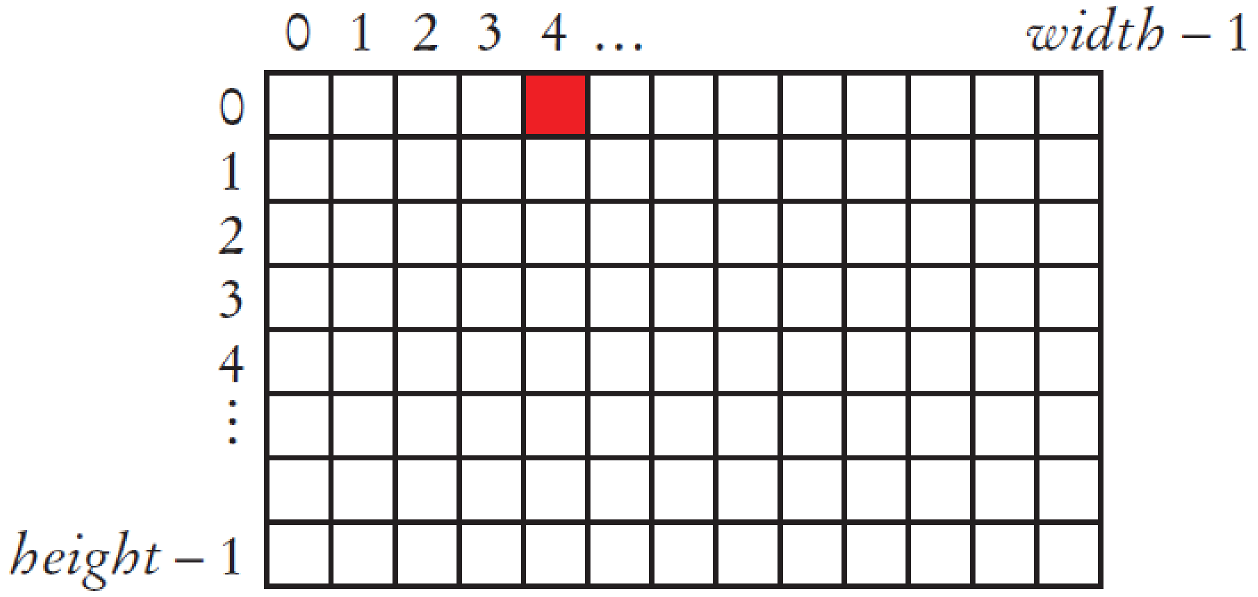
```
filename = "queen-mary.gif"
image = GraphicsImage(filename)
```

- We draw the image on the canvas of a `GraphicsWindow`

```
win = GraphicsWindow()
canvas = win.canvas()
canvas.drawImage(image)
win.wait()
```

Filtering an Image

- To filter an image, you must get the red, green, and blue component values for each pixel.
    - The pixels are organized into a two-dimensional grid of size *width* × *height*:
    - The rows and columns are numbered sequentially starting at 0, with pixel (0, 0) in the upper-left corner.
    - The row numbers range from 0 to *height* – 1; the column numbers from 0 to *width* – 1.



Accessing the Component Values of a Pixel

- We use the `getRed`, `getGreen` and `getBlue` methods

```
red = image.getRed(0, 4)
green = image.getGreen(0, 4)
blue = image.getBlue(0, 4)
```

- To create the negative of an image:

```
newRed = 255 - red
newGreen = 255 - green
newBlue = 255 – blue
```

- And then update the pixel

image.setPixel(0, 4, newRed, newGreen, newBlue)

The Pseudocode

```
width = image.width()
height = image.height()
for row in range(height) :
   for col in range(width) :
      Get the current pixel color.
      Filter the pixel.
      Set the pixel to the new color.
image.save("negative" + filename)
```

`GraphicsImage` Methods

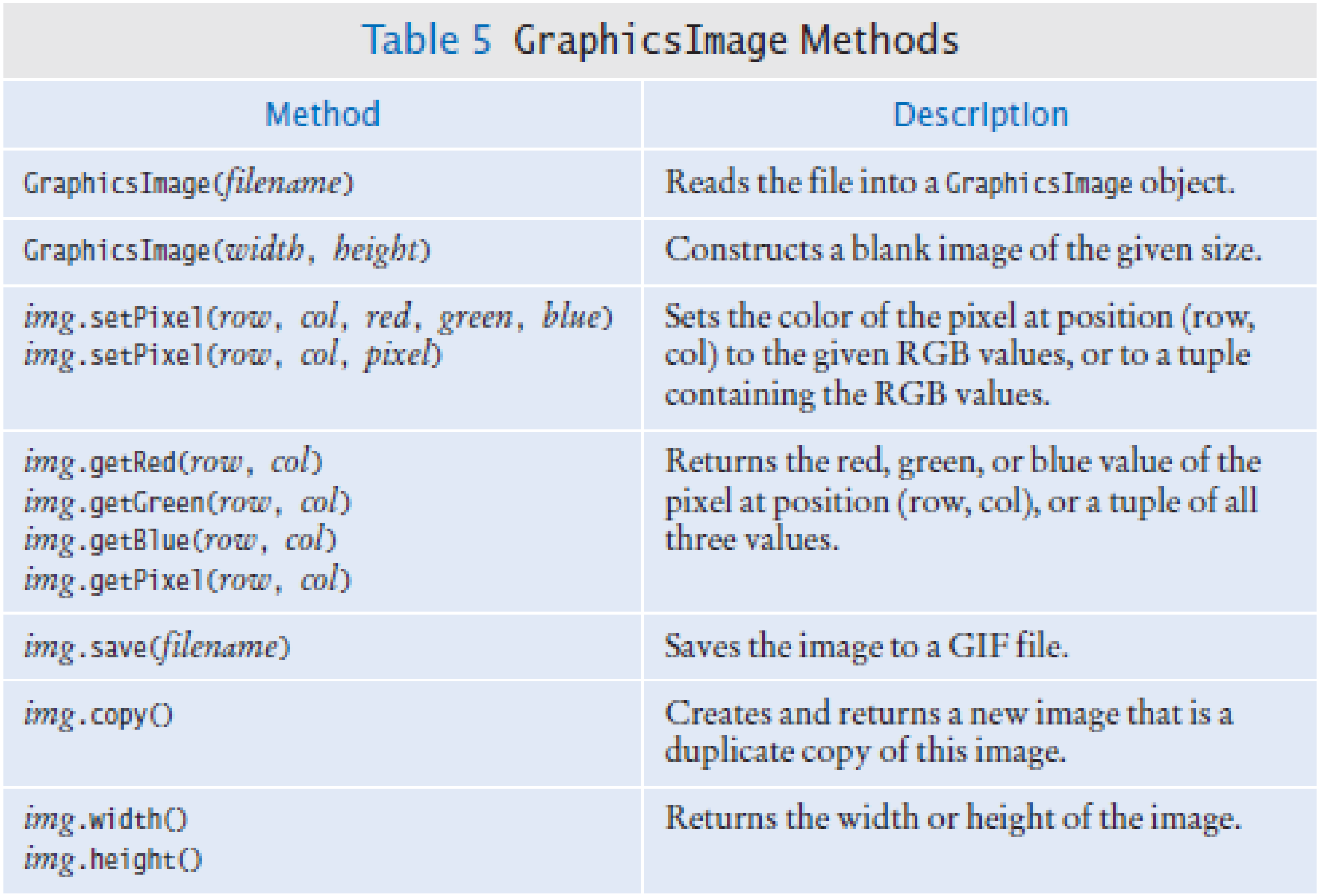


Table 5 GraphicsImage Methods

Method	Description
`GraphicsImage(`*filename*`)`	Reads the file into a `GraphicsImage` object.
`GraphicsImage(`*width*`, `*height*`)`	Constructs a blank image of the given size.
img`.setPixel(`*row*`, `*col*`, `*red*`, `*green*`, `*blue*`)` *img*`.setPixel(`*row*`, `*col*`, `*pixel*`)`	Sets the color of the pixel at position (row, col) to the given RGB values, or to a tuple containing the RGB values.
img`.getRed(`*row*`, `*col*`)` *img*`.getGreen(`*row*`, `*col*`)` *img*`.getBlue(`*row*`, `*col*`)` *img*`.getPixel(`*row*`, `*col*`)`	Returns the red, green, or blue value of the pixel at position (row, col), or a tuple of all three values.
img`.save(`*filename*`)`	Saves the image to a GIF file.
img`.copy()`	Creates and returns a new image that is a duplicate copy of this image.
img`.width()` *img*`.height()`	Returns the width or height of the image.

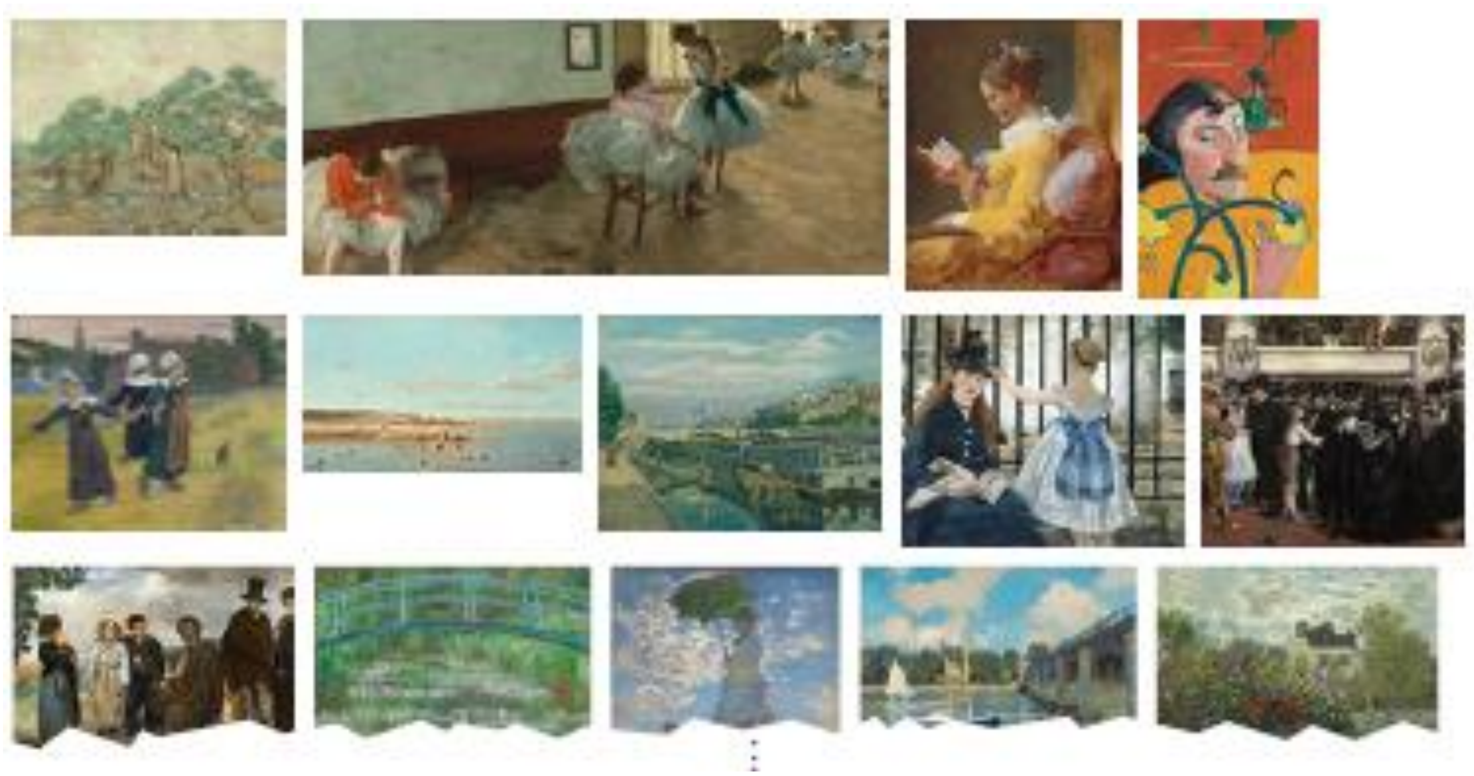
Problem Solving: Solve a Simpler Problem First

Simplify a Complex Problem

- As we learn more about programming, the complexity of the tasks we are solving increases
- When we are faced with a complex task we should apply a critical skill:
  - Simplifying the problem and solving the simpler problem first
- Our simplification (AKA problem decomposition) skills improve with practice

A Sample Problem

- Our assignment is to arrange pictures, lining them up along the top edges, separating them with small gaps, and starting a new row whenever you run out of room in the current row.
  - This sounds simple, right?



A Simple Plan

- Let’s develop a plan that solves a set of simpler (increasing in complexity) problems

1. Draw one picture.

2. Draw two pictures next to each other.

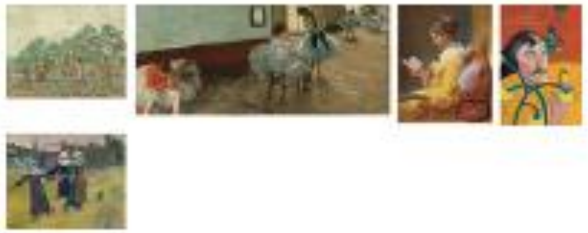
3. Draw two pictures with a gap between them.

Increase the Complexity

4. Draw three pictures with a gap between them.

5. Draw all pictures in a long row.

6. Draw a row of pictures until you run out of room, then put one more picture in the next row.



Implementing Our Plan

1. Specify the canvas coordinates where the upper left corner of the first image should be placed
2. Then place the next picture after the first after the first
   - It needs to be drawn so that its left-most edge is positioned at the right-most *x*-coordinate of the preceding picture
   - This can be determined by obtaining the width of the first picture and using that value as the *x*-coordinate for the second picture
3. Separate the two pictures with a gap
4. To draw the third picture, it’s not sufficient to know the width of the preceding picture.
   - We also need to know the *x*-coordinate where it was drawn so we can add that value to the width of the preceding image, plus the gap between the images

Implementing our Plan

5. Now let’s put all of the pictures in a row
   - Load the pictures in a loop, and then put each picture to the right of the one that preceded it.
   - In each iteration, you need to track two pictures: the one that is being loaded, and the one that preceded it

6. We don’t want to have all pictures in a single row
   - The right margin of a picture should not extend past MAX_WIDTH
   - If the image doesn’t fit we need to put it on the next row, below all the pictures in the current row
   - We’ll set a variable maxY to the maximum *y*-coordinate of all placed pictures, updating it whenever a new picture is placed

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 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.