Chapter Nine

OBJECTS AND CLASSES

Chapter Goals

- To understand the concepts of classes, objects and encapsulation
- To implement instance variables, methods and constructors
- To be able to design, implement, and test your own classes
- To understand the behavior of object references

In this chapter, you will learn how to discover, specify, and implement your own classes, and how to use them in your programs.

Contents

- Object-Oriented Programming
- Implementing a Simple Class
- Specifying the Public Interface of a Class
- Designing the Data Representation
- Constructors
- Implementing Methods
- Testing a Class
- Problem Solving: Tracing Objects
- Problem Solving: Patterns for Object data
- Object References
- Application: Writing a Fraction Class

Object-Oriented Programming

- You have learned structured programming
  - Breaking tasks into subtasks
  - Writing re-usable methods to handle tasks
- We will now study Objects and Classes
  - To build larger and more complex programs
  - To model objects we use in the world

A class describes objects with the same behavior.
For example, a Car class describes all passenger vehicles that have a certain capacity and shape.

Objects and Programs

- You have learned how to structure your programs by decomposing tasks into functions
  - Experience shows that it does not go far enough
  - It is difficult to understand and update a program that consists of a large collection of functions
- To overcome this problem, computer scientists invented **object-oriented programming**, a programming style in which tasks are solved by collaborating objects
- Each object has its own set of data, together with a set of methods that act upon the data

Objects and Programs

- You have already experienced this programming style when you used strings, lists, and file objects. Each of these objects has a set of methods
- For example, you can use the `insert()` or `remove()` methods to operate on list objects

Python Classes

- A class describes a set of objects with the same behavior.
  - For example, the `str` class describes the behavior of all strings
  - This class specifies how a string stores its characters, which methods can be used with strings, and how the methods are implemented.
  - For example, when you have a `str` object, you can invoke the `upper method`:

```
"Hello, World".upper()
```

String object

Method of class String

Python Classes

- In contrast, the `list` class describes the behavior of objects that can be used to store a collection of values
- This class has a different set of methods
- For example, the following call would be illegal—the `list` class has no `upper()` method

```
["Hello", "World"].upper()
```

- However, `list` has a `pop()` method, and the following call is legal

```
["Hello", "World"].pop()
```

Public Interfaces

- The set of all methods provided by a class, together with a description of their behavior, is called the public interface of the class
- When you work with an object of a class, you do not know how the object stores its data, or how the methods are implemented
  - You need not know how a `str` object organizes a character sequence, or how a list stores its elements
- All you need to know is the public interface—which methods you can apply, and what these methods do

Public Interfaces

- The process of providing a public interface, while hiding the implementation details, is called **encapsulation**
- If you work on a program that is being developed over a long period of time, it is common for implementation details to change, usually to make objects more efficient or more capable
  - When the implementation is hidden, the improvements do not affect the programmers who use the objects

Implementing a Simple Class

- Example:
- Tally Counter: A class that models a mechanical device that is used to count people
  - For example, to find out how many people attend a concert or board a bus
- What should it do?
  - Increment the tally
  - Get the current total

Using the `Counter` Class

- First, we construct an object of the class (object construction will be covered shortly):
- In Python, you don't explicitly declare instance variables
  - Instead, when one first assigns a value to an instance variable, the instance variable is created

```
tally = Counter()   # Creates an instance
```

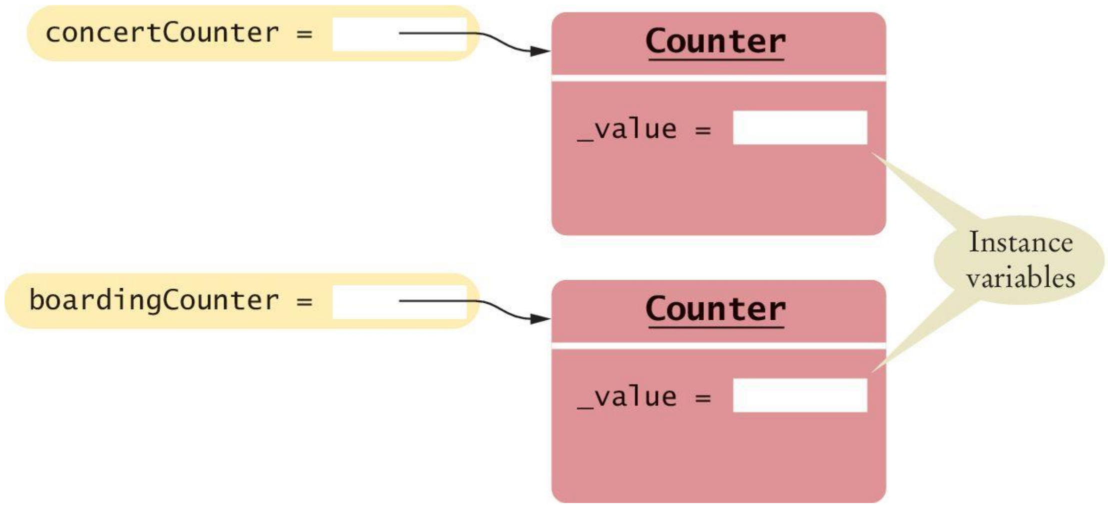
Using the **`Counter`** Class

- Next, we invoke methods on our object

```
tally.reset()
tally.click()
tally.click()
result = tally.getValue()  # Result is 2
tally.click()
result = tally.getValue() # Result is 3
```

Instance Variables

- An object stores its data in **instance variables**
- An *instance* of a class is an object of the class
- In our example, each `Counter` object has a single instance variable named `_value`
  - For example, if `concertCounter` and `boardingCounter` are two objects of the `Counter` class, then each object has its own `_value` variable



Instance Variables

- Instance variables are part of the implementation details that should be hidden from the user of the class
  - With some programming languages an instance variable can only be accessed by the methods of its own class
  - The Python language does not enforce this restriction
  - However, the underscore indicates to class users that they should not directly access the instance variables

Class Methods

- The methods provided by the class are defined in the class body
- The `click()` method advances the `_value` instance variable by 1

```
def click(self) :
    self._value = self._value + 1
```

- A method definition is very similar to a function with these exceptions:
  - A method is defined as part of a class definition
  - The first parameter variable of a method is called `self`

Class Methods and Attributes

- Note how the `click()` method increments the instance variable `_value`
- *Which* instance variable? The one belonging to the object on which the method is invoked
  - In the example below the call to `click()` advances the `_value variable` of the `concertCounter` object
  - No argument was provided when the `click()` method was called *even though the definition includes the `self` parameter* variable

  - The `self` parameter variable refers to the object on which the method was invoked `concertCounter` in this example

```
concertCounter.click()
```

Example of Encapsulation

- The `getValue()` method returns the current `_value`:

```
def getValue(self) :
    return self._value
```

- This method is provided so that users of the `Counter` class can find out how many times a particular counter has been clicked
- A class user should not directly access any instance variables
- Restricting access to instance variables is an essential part of encapsulation

Complete Simple Class Example

```python
from counter import Counter

tally = Counter()
tally.reset()
tally.click()
tally.click()

result = tally.getValue()
print("Value:", result)

tally.click()
result = tally.getValue()
print("Value:", result)
```

```python
class Counter :
    ## Gets the current value of this counter.
    #  @return the current value
    #
    def getValue(self) :
        return self._value

    ## Advances the value of this counter by 1.
    #
    def click(self) :
        self._value = self._value + 1

    ## Resets the value of this counter to 0.
    #
    def reset(self) :
        self._value = 0
```

Program execution

```
Value: 2
Value: 3
```

Public Interface of a Class

- When you design a class, start by specifying the public interface of the new class
    - What tasks will this class perform?
    - What methods will you need?
    - What parameters will the methods need to receive?

Example Public Interface

- Example: A Cash Register Class

Task	Method
Add the price of an item	addItem(price)
Get the total amount owed	getTotal()
Get the count of items purchased	getCount()
Clear the cash register for a new sale	clear()

  - Since the ‘`self`’ parameter is required for all methods it was excluded for simplicity

Writing the Public Interface

```
## A simulated cash register that tracks the item count and the total amount due.
#
class CashRegister :
   ## Adds an item to this cash register.
   # @param price: the price of this item
   #
   def addItem(self, price) :
      # Method body


   ##  Gets the price of all items in the current sale.
   #  @return the total price
   #
   def getTotal(self):  ...
```

Class comments document the class and the behavior of each method

The method declarations make up the *public interface* of the class

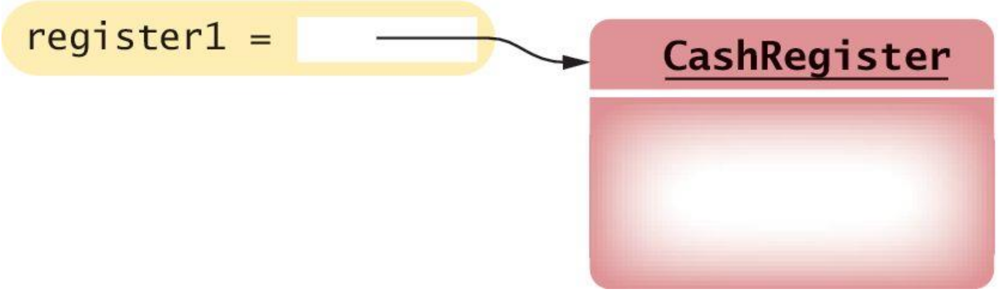
The data and method bodies make up the *private implementation* of the class

Using the Class

- After defining the class we can now construct an object:

```
register1 = CashRegister()
   # Constructs a CashRegister object
```

- This statement defines the `register1` variable and initializes it with a reference to a new `CashRegister` object



Using Methods

- Now that an object has been constructed, we are ready to invoke a method:

```
register1.addItem(1.95) # Invokes a method.
```

Accessor and Mutator Methods

- Many methods fall into two categories:

  1) *Accessor Methods*: '**get**' methods
     - Asks the object for information without changing it
     - Normally returns the current value of an attribute

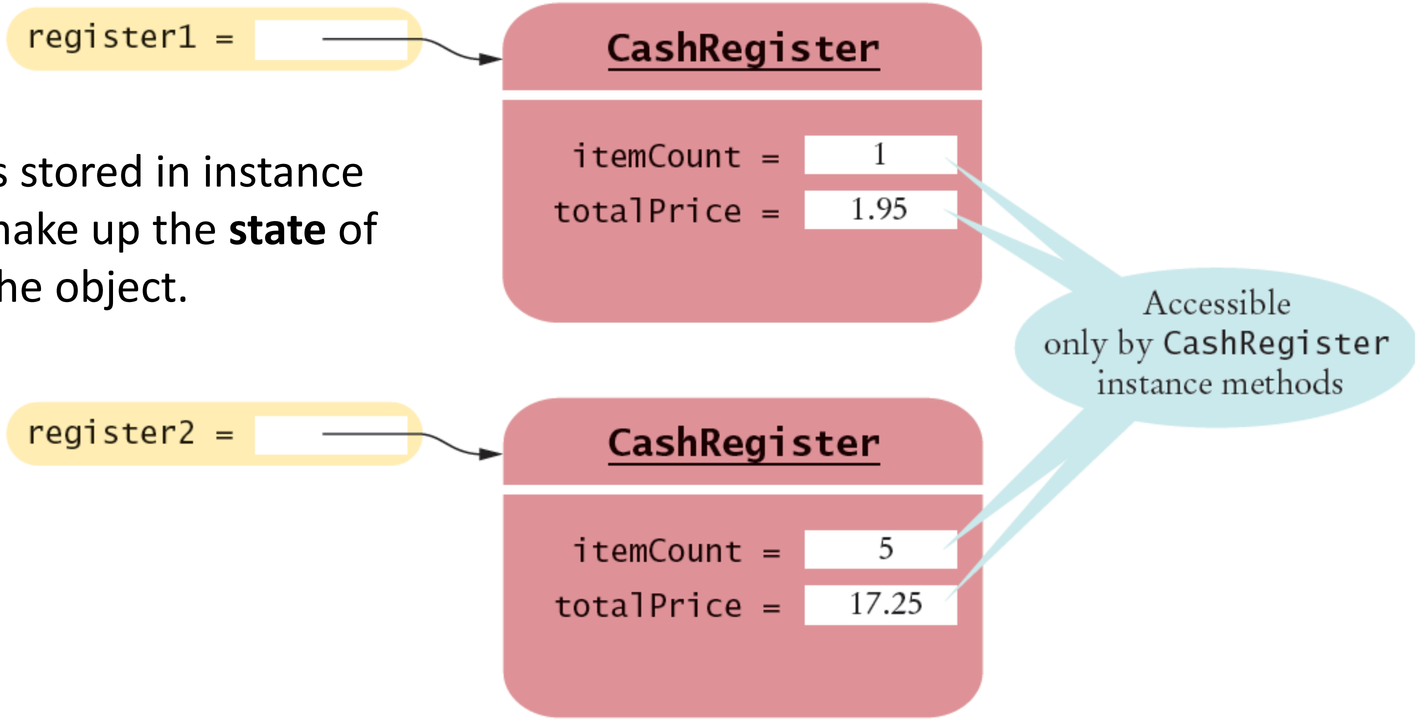
```
def getTotal(self):
def getCount(self):
```

  2) *Mutator Methods*: '**set**' methods
     - Changes values in the object
     - Usually take a parameter that will change an instance variable

```
def addItem(self, price):
def clear(self):
```

Instance Variables of Objects

- Each object of a class has a separate set of instance variables



The values stored in instance variables make up the **state** of the object.

Designing the Data Representation

- An object stores data in instance variables
  - Variables declared inside the class
  - All methods inside the class have access to them
    - Can change or access them
  - What data will our `CashRegister` methods need?

Task	Method	Data Needed
Add the price of an item	addItem(price)	total, count
Get the total amount owed	getTotal()	total
Get the count of items purchased	getCount()	count
Clear cash register for a new sale	clear()	total, count

An object holds instance variables that are accessed by methods

Programming Tip 9.1

- All instance variables should be private and most methods should be public
  - Although most object-oriented languages provide a mechanism to explicitly hide or protect private members from outside access, Python does not
- It is common practice among Python programmers to use names that begin with a single underscore for private instance variables and methods
  - The single underscore serves as a flag to the class user that those members are private

Programming Tip 9.1

- You should always use encapsulation, in which all instance variables are private and are only manipulated with methods
- Typically, methods are public
  - However, sometimes you have a method that is used only as a helper method by other methods
  - In that case, you should identify the helper method as private by using a name that begins with a single underscore

Constructors

- A *constructor* is a method that initializes instance variables of an object
  - It is automatically called when an object is created

```
# Calling a method that matches the name of the class
# invokes the constructor
register = CashRegister()
```

- Python uses the special name `_ _init_ _` for the constructor because its purpose is to initialize an instance of the class:

```
def _ _init_ _(self) :
    self._itemCount = 0
    self._totalPrice = 0
```

Default and Named Arguments

- Only one constructor can be defined per class
- But you can a define constructor with *default argument values* that simulate multiple definitions

```
class BankAccount :
    def __init__(self, initialBalance = 0.0) :
        self._balance = initialBalance
```

- If no value is passed to the constructor when a `BankAccount` object is created the default value will be used

```
joesAccount = BankAccount()   # Balance is set to 0
```

Default and Named Arguments

- If a value is passed to the constructor that value will be used instead of the default one

```
joesAccount = BankAccount(499.95)
   # Balance is set to 499.95
```

- Default arguments can be used in any method and not just constructors

Syntax: Constructors

Syntax

class *ClassName* :
    def __init__(self, *parameterName*$_1$, *parameterName*$_2$, . . .) :
        constructor body

The special name `__init__` is used to define a constructor.

```
class BankAccount :
    def __init__(self) :
        self._balance = 0.0
    . . .
```

A constructor defines and initializes the instance variables.

```
class BankAccount :
    def __init__(self, initialBalance = 0.0) :
        self._balance = initialBalance
    . . .
```

There can be only one constructor per class. But a constructor can contain default arguments to provide alternate forms for creating objects.

Constructors: `Self`

- The first parameter variable of every constructor must be `self`
- When the constructor is invoked to construct a new object, the `self` parameter variable is set to the object that is being initialized

Refers to the object being initialized

```
def _ _init_ _(self) :
    self._itemCount = 0
    self._totalPrice = 0
```

```
register = CashRegister()
```

After the constructor ends this is a reference to the newly created object

Object References

```
register = CashRegister()
```

After the constructor ends this is a reference to the newly created object

- This reference then allows methods of the object to be invoked

```
print("Your total $", register.getTotal())
```

Call the method through the reference

Common Error 9.1 (1)

- After an object has been constructed, you should not directly call the constructor on that object again:

```
register1 = CashRegister()
register1._ _init_ _()   # Bad style
```

Common Error 9.1 (2)

- The constructor can set a new `CashRegister` object to the cleared state, but you should not call the constructor on an existing object. Instead, replace the object with a new one:

```
register1 = CashRegister()
register1 = CashRegister()   # OK
```

In general, you should never call a Python method that starts with a double underscore. The are intended for specific internal purposes (in this case, to initialize a newly created object).

Implementing Methods

- Implementing a method is very similar to implementing a function except that you access the instance variables of the object in the method body

```
def addItem(self, price):
    self._itemCount = self._itemCount + 1
    self._totalPrice = self._totalPrice + price
```

Task	Method
Add the price of an item	addItem(price)
Get the total amount owed	getTotal()
Get the count of items purchased	getCount()
Clear the cash register for a new sale	clear()

Syntax: Instance Methods

- Use instance variables inside methods of the class
  - Similar to the constructor, all other instance methods must include the self parameter as the first parameter
  - You must specify the `self` implicit parameter when using instance variables inside the class

Syntax

```
class ClassName :
   . . .
   def methodName(self, parameterName1, parameterName2, . . .) :
      method body
   . . .
```

```
class CashRegister :
   . . .
   def addItem(self, price) :
      self._itemCount = self._itemCount + 1
      self._totalPrice = self._totalPrice + price
   . . .
```

Every method must include the special `self` parameter variable. It is automatically assigned a value when the method is called.

Instance variables are referenced using the `self` parameter.

Local variable

Invoking Instance Methods

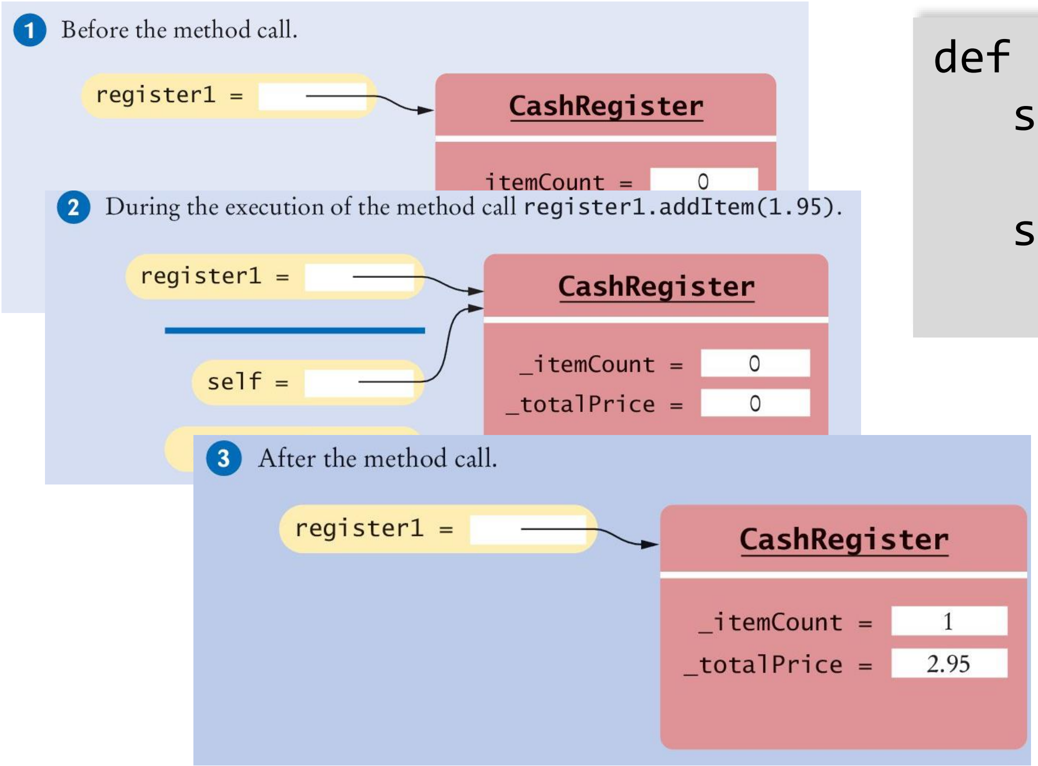
- As with the constructor, every method must include the special `self` parameter variable, and it must be listed first.
- When a method is called, a reference to the object on which the method was invoked (`register1`) is automatically passed to the `self` parameter variable:

```
register1.addItem(2.95)
```

```
def addItem(self, price):
```

Tracing The Method Call

```
register1 = CashRegister()    #1 New object
register1.addItem(2.95)       #2  Calling method
…                             #3 After method
```




```
def addItem(self, price):
   self._itemCount =
      self._itemCount + 1
   self._totalPrice =
      self._totalPrice + price
```

Accessing Instance Variables

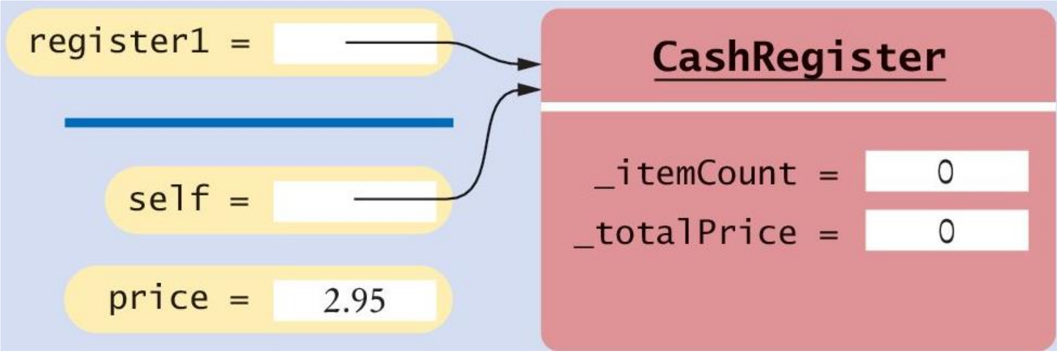
- To access an instance variable, such as `_itemCount` or `_totalPrice`, in a method, you must access the variable name through the `self` reference
  - This indicates that you want to access the instance variables of the object on which the method is invoked, and not those of some other `CashRegister` object

- The first statement in the `addItem()` method is

```
self._itemCount = self._itemCount + 1
```

Accessing Instance Variables

- Which `_itemCount` is incremented?
  - In this call, it is the `_itemCount` of the `register1` object.



Calling One Method Within Another

- When one method needs to call another method on the same object, you invoke the method on the self parameter

```
def addItems(self, quantity, price) :
    for i in range(quantity) :
        self.addItem(price)
```

Example: CashRegister.py (1)

```
class CashRegister :
    ## Constructs a cash register with cleared item count and total.
    #
    def __init__(self) :
        self._itemCount = 0
        self._totalPrice = 0.0

    ## Adds an item to this cash register.
    #  @param price the price of this item
    #
    def addItem(self, price) :
        self._itemCount = self._itemCount + 1
        self._totalPrice = self._totalPrice + price

    ## Gets the price of all items in the current sale.
    #  @return the total price
    #
    def getTotal(self) :
        return self._totalPrice

    ## Gets the number of items in the current sale.
    #  @return the item count
    #
    def getCount(self) :
        return self._itemCount

    ## Clears the item count and the total.
    #
    def clear(self) :
        self._itemCount = 0
        self._totalPrice = 0.0
```

Programming Tip 9.2

- Instance variables should only be defined in the constructor
- All variables, including instance variables, are created at run time
  - There is nothing to prevent you from creating instance variables in any method of a class
- The constructor is invoked before any method can be called, so any instance variables that were created in the constructor are sure to be available in all methods

Class Variables

- They are a value properly belongs to a class, not to any object of the class
- Class variables are often called “static variables”
- Class variables are declared at the same level as methods
  - In contrast, instance variables are created in the constructor

Class Variables: Example (1)

- We want to assign bank account numbers sequentially: the first account is assigned number 1001, the next with number 1002, and so on

- To solve this problem, we need to have a single value of `_lastAssignedNumber` that is a property of the *class*, not any object of the class

```
class BankAccount :
    _lastAssignedNumber = 1000 # A class variable
    def _ _init_ _(self) :
        self._balance = 0
        BankAccount._lastAssignedNumber =
           BankAccount._lastAssignedNumber + 1
        self._accountNumber =
           BankAccount._lastAssignedNumber
```

Class Variables: Example (2)

- Every `BankAccount` object has its own `_balance` and `_account-Number` instance variables, but there is only a single copy of the `_lastAssignedNumber` variable
- That variable is stored in a separate location, outside any `BankAccount` object
- Like instance variables, class variables should always be private to ensure that methods of other classes do not change their values. However, class *constants* can be public

Class Variables: Example (3)

- For example, the `BankAccount` class can define a public constant value, such as

```
class BankAccount :
    OVERDRAFT_FEE = 29.95
    . . .
```

- Methods from any class can refer to such a constant as `BankAccount.OVERDRAFT_FEE`

Testing a Class

- In the long run, your class may become a part of a larger program that interacts with users, stores data in files, and so on
- You should always test your class in isolation integrating a class into a program
- Testing in isolation, outside a complete program, is called **unit testing**

Choices for Testing: The Python shell

- Some interactive development environments provide access to the Python shell in which individual statements can be executed
- You can test a class simply by constructing an object, calling methods, and verifying that you get the expected return values

```
>>> from cashregister import CashRegister
>>> reg = CashRegister()
>>> reg.addItem(1.95)
>>> reg.addItem(0.95)
>>> reg.addItem(2.50)
>>> print(reg.getCount())
3
>>> print(reg.getTotal())
5.4
>>>
```

Choices for Testing: Test Drivers

- Interactive testing is quick and convenient but it has a drawback
  - When you find and fix a mistake, you need to type in the tests again
- As your classes get more complex, you should write tester programs
  - A tester program is a driver module that imports the class and contains statements to run methods of your class

Steps Performed by a Tester Program

1. Construct one or more objects of the class that is being tested
2. Invoke one or more methods
3. Print out one or more results
4. Print the expected results
5. Compare the computed results with the expected

Example Test Program

- It runs and tests the methods of the `CashRegister` class

```
from cashregister import CashRegister

register1 = CashRegister()
register1.addItem(1.95)
register1.addItem(0.95)
register1.addItem(2.50)
print(register1.getCount())
print("Expected: 3")
print("%.2f" % register1.getTotal())
print("Expected: 5.40")
```

Program execution

```
3
Expected: 3
5.40
Expected: 5.40
```

Test Drivers: Plan Beforehand

- Thinking about the sample program:
  - We add three items totaling $5.40
  - When displaying the method results, we also display messages that describe the values we expect to see
- This is a very important step. You want to spend some time thinking about what the expected result is before you run a test program
- This thought process will help you understand how your program should behave, and it can help you track down errors at an early stage

Test Drivers: Using Modules

- You need to import the class you are testing (here, the `CashRegister` class) into the driver module:

```
from cashregister import CashRegister
```

- The specific details for running the program depend on your development environment

Steps to Implementing a Class

1) Get an informal list of responsibilities for your objects

Deposit funds.
Withdraw funds.
Add interest.

- There is a hidden responsibility as well. We need to be able to find out how much money is in the account.

Get balance.

Steps to Implementing a Class

- 2) Specify the public interface
  - Constructor

    ```
    def __init__(self, initialBalance = 0.0) :
    ```

  - Mutators

    ```
    def deposit(self, amount) :
    def withdraw(self, amount) :
    def addInterest(self, rate) :
    ```

  - Accessors

    ```
    def getBalance(self) :
    ```

- 3) Document the public interface

```
## Constructs a bank account with a given balance.
#  @param initialBalance the initial account balance (default = 0.0)
#
```

Steps to Implementing a Class

4) Determine the instance variables

```
self._balance = initialBalance
```

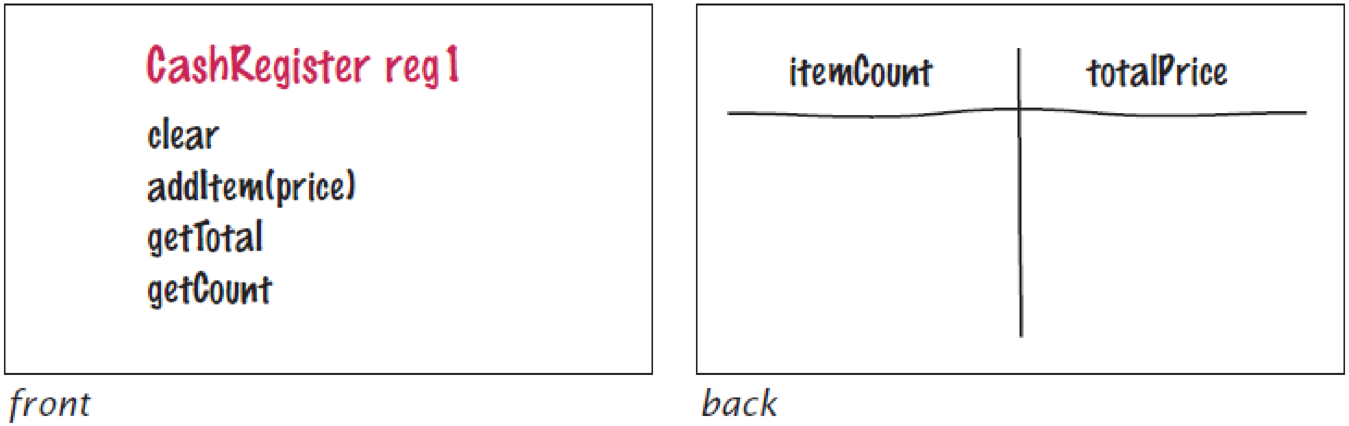
5) Implement constructors and methods

```
def getBalance(self) :
    return self._balance
```

6) Test your class

Problem Solving: Tracing Objects

- Use an Index card for each object:



- An object is manipulated through the public interface (front of the card).
- The encapsulated data is on the back of the card

Mutator Methods and Cards

- As mutator methods are called, keep track of the value of instance variables

```
register2 = CashRegister(7.5)   # 7.5 percent sales tax
register2.addItem(3.95, False)  # Not taxable
register2.addItem(19.95, True)  # Taxable
```

itemCount	totalPrice	taxableTotal	taxRate
~~0~~	~~0~~	~~0~~	7.5
~~1~~	~~3.95~~		
2	23.90	19.95	

Problem Solving: Patterns for Object Data

- Common patterns when designing instance variables
  - Keeping a Total
  - Counting Events
  - Collecting Values
  - Managing Object Properties
  - Modeling Objects with Distinct States
  - Describing the Position of an Object

Patterns: Keeping a Total

- Examples
  - Bank account balance
  - Cash Register total
  - Car gas tank fuel level
- Variables needed
  - `totalPrice`
- Methods Required
  - `add (addItem)`
  - `clear`
  - `getTotal`

```
class CashRegister :
    def addItem(self, price):
        self._itemCount =
           self._itemCount + 1
        self._totalPrice =
           self._totalPrice + price

    def clear(self):
        self._itemCount = 0
        self._totalPrice = 0.0

    def getTotal(self):
        return self._totalPrice
```

Patterns: Counting Events

- Examples
  - Cash Register items
  - Bank transaction fee
- Variables needed
  - itemCount
- Methods Required
  - Add
  - Clear
  - Optional: getCount

```
class CashRegister:
    def addItem(self, price):
        self._itemCount =
           self._itemCount + 1
        self._totalPrice =
           self._totalPrice + price

    def clear(self):
        self._itemCount = 0
        self._totalPrice = 0.0

    def getCount(self):
        return self._itemCount
```

Patterns: Collecting Values

- Examples
  - Multiple choice question
  - Shopping cart
- Storing values
  - List
- Constructor
  - Initialize to empty collection
- Methods Required
  - Add

```
class Cart:
    def _ _init_ _(self) :
        self._choices = []

    def addItem(self, name) :
       self._choices.append
          (choice)
```

Patterns: Managing Properties

A property of an object can be set and retrieved

- Examples
  - Student: name, ID
- Constructor
  - Set a unique value
- Methods Required
  - set
  - get

```
class Student :
    def _ _init_ _
       (self, aName, anId) :
        self._name = aName
        self._id = anId

    def getName(self) :
        return self._name

    def setName(self, newName) :
        self._name = newName

    def getId(self) :
        return self._id

    # No setId method
```

Patterns: Modeling Object States

Some objects can be in one of a set of distinct states

- Example: A fish
  - Hunger states:
    - Not Hungry
    - Somewhat Hungry
    - Very Hungry
- Methods will change the state
  - eat
  - move

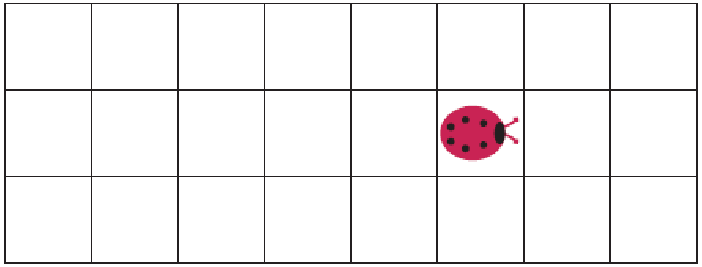
```
class Fish:
   NOT_HUNGRY = 0
   SOMEWHAT_HUNGRY = 1
   VERY_HUNGRY = 2

   def eat(self) :
      self._hungry =
      Fish.NOT_HUNGRY

   def move(self) :
      if self._hungry <
        Fish.VERY_HUNGRY :
         self._hungry =
         self._hungry + 1
```

Patterns: Object Position

- Examples
  - Game object
  - Bug (on a grid)
  - Cannonball
- Storing values
  - Row, column, direction, speed. . .
- Methods Required
  - move
  - turn



```
class Bug:
    def _ _init_ _
       (self, aRow, aColumn,
        aDirection, speed) :
        self._row = aRow
        self._column = aColumn
        self._direction =
           direction
# 0 = N, 1 = E, 2 = S, 3 = W
        . . .

  def moveOneUnit(self):
      if (self._direction == 0):
          self._row =
             self._row - 1
      . . .
```

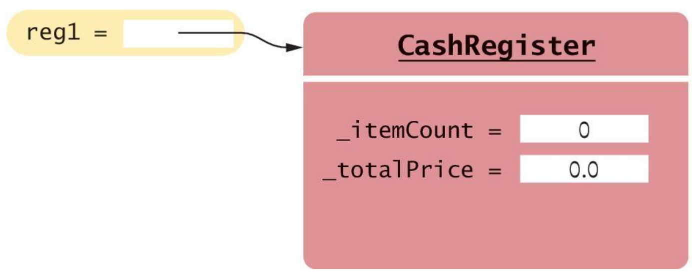
Object References

- In Python, a variable does not actually hold an object
- It merely holds the *memory location* of an object
- The object itself is stored in another location:

```
reg1 = CashRegister
```

The constructor returns a reference to the new object, and that reference is stored in the reg1 variable.

Reference

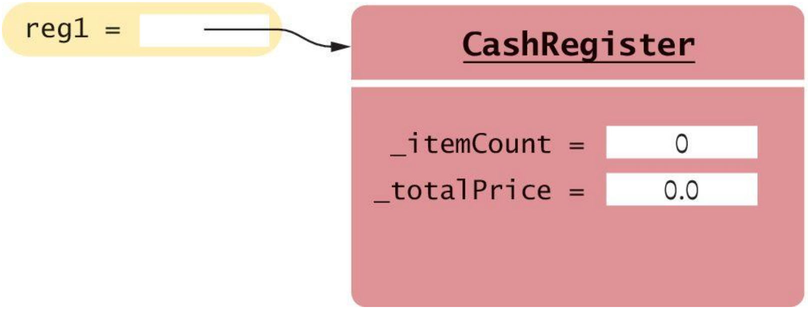


Object

Shared References

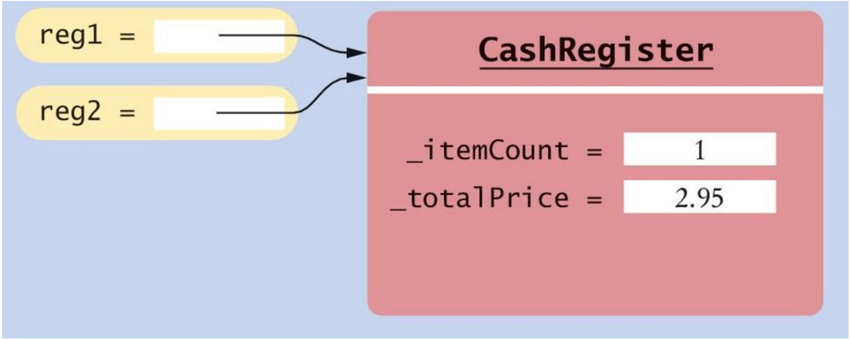
- Multiple object variables may contain references to the same object ('aliases')
  - Single Reference

```
reg1 = CashRegister
```



  - Shared References

```
reg2 = reg1
```



The internal values can be changed through either reference

Testing if References are Aliases

- Checking if references are aliases, use the `is` or the `not is` operator:

```
if reg1 is reg2 :
    print("The variables are aliases.")
if reg1 is not reg2 :
    print("The variables refer to different objects.")
```

- Checking if the data contained within objects are equal use the `==` operator:

```
if reg1 == reg2 :
    print("The objects contain the same data.")
```

The None reference

- A reference may point to ‘no’ object
  - You cannot invoke methods of an object via a None reference – causes a run-time error

```
reg = None
print(reg.getTotal())   # Runtime Error!
```

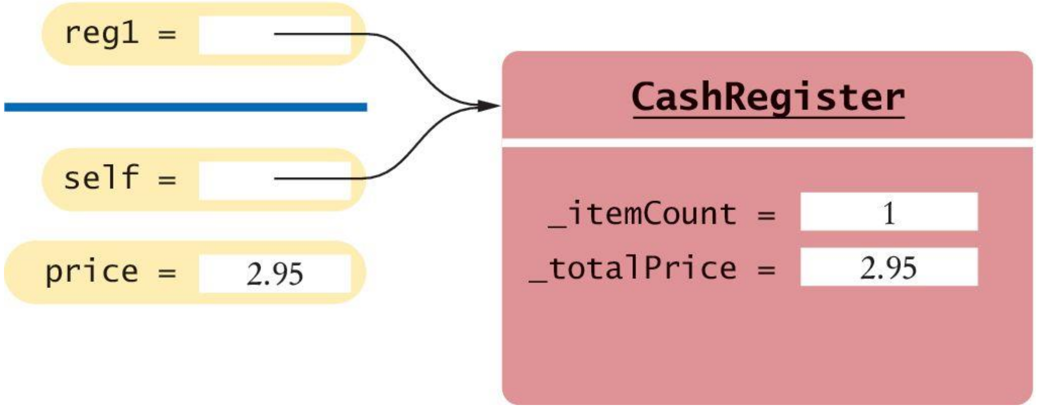
  - To test if a reference is None before using it:

```
middleInitial = None   # No middle initial

if middleInitial is None :
  print(firstName, lastName)
else :
  print(firstName, middleInitial + ".", + lastName)
```

The `self` reference

- Every method has a reference to the object on which the method was invoked, stored in the `self` parameter variable
  - It is a reference to the object the method was invoked on:



  - It can clarify when instance variables are used:

```
def addItem(self, price):
  self.itemCount = self.itemCount + 1
  self.totalPrice = self.totalPrice + price
```

Using `self` to Invoke Other Methods

- You can also invoke a method on `self`:

```
def _ _init_ _(self) :
    self.clear()
```

  - In a constructor, `self` is a reference to the object that is being constructed
  - The `clear()` method is invoked on that object

Passing `self` as a Parameter

- Suppose, for example, you have a `Person` class with a method `likes(self, other)` that checks, perhaps from a social network, whether a person likes another

```
def isFriend(self, other) :
    return self.likes(other) and other.likes(self)
```

Object Lifetimes: Creation

- When you construct an object with a constructor, the object is created, and the `self` variable of the constructor is set to the memory location of the object
  - Initially, the object contains no instance variables.
  - As the constructor executes statements such as instance variables are added to the object

```
self._itemCount = 0
```

- Finally, when the constructor exits, it returns a reference to the object, which is usually captured in a variable:

```
reg1 = CashRegister()
```

Object Lifetimes: Cleaning Up

- The object, and all of its instance variables, stays alive as long as there is at least one reference to it.
- When an object is no longer referenced at all, it is eventually removed by a part of the virtual machine called the “garbage collector”

```
reg1 = CashRegister()   # New object referenced by reg1
reg1 = CashRegister()
   # Another object referenced by reg1
   # First object will be garbage collected
```

Writing a Fraction Class

- So far we have worked with floating-point numbers but computers store binary values, so not all real numbers can be represented precisely
- In applications where the precision of real numbers is important, we can use *rational numbers* to store exact values
  - This helps to reduce or eliminate round-off errors that can occur when performing arithmetic operations
  - A rational number is a number that can be expressed as a ratio of two integers: 7/8
  - The top value is called the *numerator* and the bottom value, which cannot be zero, is called the *denominator*

Designing the Fraction Class

- We want to use our rational numbers as we would use integers and floating point values
- Thus, our `Fraction` class must perform the following operations:
  1. Create a rational number
  2. Access the numerator and denominator values, individually
  3. Determine if the rational number is negative or zero
  4. Perform normal mathematical operations on two rational numbers (addition, subtraction, multiplication, division, exponentiation)
  5. Logically compare two rational numbers
  6. Produce a string representation of the rational number
- The objects of the Fraction class will be **immutable** because none of the operations modify the objects' instance variables

Required Data Attributes

- Because a rational number consists of two integers, we need two instance variables to store those values:

```
self._numerator = 0
self._denominator = 1
```

- At no time should the rational number be converted to a floating-point value or we will lose the precision gained from working with rational numbers

Representing Values Equivalently

- Signed values
  - Negative and positive rational numbers each have two forms that can be used to specify the corresponding value
  - Positive values can be indicated as 1/2 or –1/–2, and negative values as –2/5 or 2/–5
  - When performing an arithmetic operation or logically comparing two rational numbers, it will be much easier if we have a single way to represent a negative value
  - For simplicity, we choose to set only the numerator to a negative value when the rational number is negative, and both the numerator and denominator will be positive integers when the rational number is positive

Representing Values Equivalently

- Equivalent fractions
  - For example, 1/4 can be written as 1/4, 2/8, 16/64, or 123/492
  - It will be much easier to perform the operation if the number is stored in reduced form

The Constructor (1)

- Because `Fraction` objects are immutable, their values must be set when they are created. This requires parameter variables for both the numerator and denominator

```
def _ _init_ _(self, numerator, denominator) :
```

- The method must check for special cases:
  - Zero denominators
  - The number represents zero or a negative number

The Constructor

```
def _ _init_ _(self, numerator = 0, denominator = 1) :
    if denominator == 0 :
        raise ZeroDivisionError("Denominator cannot be zero.")
    if numerator == 0 :
        self._numerator = 0
        self._denominator = 1
    else :
        if (numerator < 0 and denominator >= 0 or
            numerator >= 0 and denominator < 0) :
           sign = -1
        else :
           sign = 1
```

The Constructor

```
a = abs(numerator)
b = abs(denominator)
while a % b != 0 :
    tempA = a
    tempB = b
    a = tempB
    b = tempA % tempB
self._numerator = abs(numerator)       # b * sign
self._denominator = abs(denominator)   #b
```

Testing the Constructor

```
frac1 = Fraction(1, 8) # Stored as 1/8
frac2 = Fraction(-2, -4) # Stored as 1/2
frac3 = Fraction(-2, 4) # Stored as -1/2
frac4 = Fraction(3, -7) # Stored as -3/7
frac5 = Fraction(0, 15) # Stored as 0/1
frac6 = Fraction(8, 0) # Error! exception is raised.
```

Comparing Fractions (1)

- In Python, we can define and implement methods that will be called automatically when a standard Python operator (+, *, ==, <) is applied to an instance of the class
- For example, to test whether two fractions are equal, we could implement a method:
  - `isequal()` and use it as follows:

```
if frac1.isequal(frac2) :
    print("The fractions are equal.")
```

Comparing Fractions (2)

- Of course, we would prefer to use the operator ==
- This is achieved by defining the special method:

  `_ _eq_ _():`

```
def _ _eq_ _(self, rhsValue) :
    return (self._numerator == rhsValue.numerator and
            self._denominator == rhsValue.denominator)
```

- Automatically calls this method when we compare two `Fraction` objects using the == operator:

```
if frac1 == frac2 : # Calls frac1._ _eq_ _(frac2)
    print("The fractions are equal.")
```

Special Methods

- Some special methods are called when an instance of the class is passed to a built-in function. For example, suppose you attempt to convert a `Fraction` object to a floating point number using the `float()` function:

```
x = float(frac1)
```

- Then the `_ _float_ _()` special method is called.
- Here is a definition of that method:

```
def _ _float_ _(self) :
    return self._numerator / self._denominator
```

Common Special Methods

Table 1 Common Special Methods

Expression	Method Name	Returns	Description
x + y	__add__(self, y)	object	Addition
x - y	__sub__(self, y)	object	Subtraction
x * y	__mul__(self, y)	object	Multiplication
x / y	__truediv__(self, y)	object	Real division
x // y	__floordiv__(self, y)	object	Floor division
x % y	__mod__(self, y)	object	Modulus
x ** y	__pow__(self, y)	object	Exponentiation
x == y	__eq__(self, y)	Boolean	Equal
x != y	__ne__(self, y)	Boolean	Not equal

Common Special Methods

Table 1 Common Special Methods

x < y	__lt__(self, y)	Boolean	Less than
x <= y	__le__(self, y)	Boolean	Less than or equal
x > y	__gt__(self, y)	Boolean	Greater than
x >= y	__ge__(self, y)	Boolean	Greater than or equal
-x	__neg__(self)	object	Unary minus
abs(x)	__abs__(self)	object	Absolute value
float(x)	__float__(self)	float	Convert to a floating-point value
int(x)	__int__(self)	integer	Convert to an integer value
str(x) print(x)	__repr__(self)	string	Convert to a readable string
x = ClassName()	__init__(self)	object	Constructor

Addition of Fractions

- All of the arithmetic operations that can be performed on a `Fraction` object should return the result in a new `Fraction` object
- For example, when the statement below is executed, `frac1` should be added to `frac2` and the result returned as a new `Fraction` object that is assigned to the `newFrac` variable

```
newFrac = frac1 + frac2
```

Fractional Addition

- From elementary arithmetic, you know that two fractions must have a common denominator in order to add them. If they do not have a common denominator, we can still add them using the formula:

$$\frac{a}{b} + \frac{c}{d} = \frac{d \cdot a + b \cdot c}{b \cdot d}$$

Defining the Method For Addition

```
def _ _add_ _(self, rhsValue) :
    num = (self._numerator * rhsValue._denominator +
       self._denominator * rhsValue._numerator)
    den = self._denominator * rhsValue._denominator
    return Fraction(num, den)
```

Logic: Less Than

- Note that $a\,/\,b < c\,/\,d$ when $d \cdot a < b \cdot c$. (Multiply both sides with $b \cdot d$.)
- Based on this observation, the less than operation is implemented by the `_ _lt_ _()` method as follows:

```
def _ _lt_ _(self, rhsValue) :
    return (self._numerator * rhsValue._denominator
            self._denominator * rhsValue._numerator)
```

Fraction.py

```
class Fraction :
    ## Constructs a rational number initialized to zero or a user specified value.
    #  @param numerator the numerator of the fraction (default is 0)
    #  @param denominator the denominator of the fraction (cannot be 0)
    #
    def __init__(self, numerator = 0, denominator = 1) :
        # The denominator cannot be zero.
        if denominator == 0 :
            raise ZeroDivisi

        # If the rational nur
        if numerator == 0 :
            self._numerator
            self._denominatc
```

```
        # Otherwise, store the rational number in reduced form.
        else :
            # Determine the sign.
            if (numerator < 0 and denominator >= 0 or
                 numerator >= 0 and denominator < 0) :
                sign = -1
            else :
                sign = 1

            # Reduce to smallest form.
            a = abs(numerator)
            b = abs(denominator)
            while a % b != 0 :
                tempA = a
                tempB = b
                a = tempB
                b = tempA % tempB

            self._numerator = abs(numerator) // b * sign
            self._denominator = abs(denominator) // b
```

Fraction.py

```
    def __add__(self, rhsValue) :
       num = (self._numerator * rhsValue._denominator +
              self._denominator * rhsValue._numerator)
       den = self._denominator * rhsValue._denominator
       return Fraction(num, den)

    ## Subtracts a fraction from this fraction.
    #  @param rhsValue the right-hand side fraction
    #  @return a new Fraction object resulting from the subtraction
    #
    def __sub__(self, rhsValue) :
       num = (self._numerator * rhsValue._denominator -
              self._denominator * rhsValue._numerator)
       den = self._denominator * rhsValue._denominator
       return Fraction(num, den)
```

```
    def __eq__(self, rhsValue) :
       return (self._numerator == rhsValue._numerator and
               self._denominator == rhsValue._denominator)
```

Fraction.py

```
    def __lt__(self, rhsValue) :
      return (self._numerator * rhsValue._denominator <
              self._denominator * rhsValue._numerator)

    ## Determines if this fraction is not equal to another fraction.
    #  @param rhsValue the right-hand side fraction
    #  @return True if the fractions are not equal
    #
    def __ne__(self, rhsValue) :
      return not self == rhsValue

    ## Determines if this fraction is less than or equal to another fraction.
    #  @param rhsValue the right-hand side fraction
    #  @return True if this fraction is less than or equal to the other
    #
    def __le__(self, rhsValue) :
      return not rhsValue < self

    ## Determines if this fraction is greater than another fraction.
    #  @param rhsValue the right-hand side fraction
    #  @return True if this fraction is greater than the other
    #
    def __gt__(self, rhsValue) :
      return rhsValue < self

    ## Determines if this fraction is greater than or equal to another fraction.
    #  @param rhsValue the right-hand side fraction
    #  @return True if this fraction is greater than or equal to the other
    #
    def __ge__(self, rhsValue) :
      return not self < rhsValue
```

Fraction.py

```
    def __float__(self) :
        return self._numerator / self._denominator

    ## Gets a string representation of the fraction.
    #  @return a string in the format #/#
    #
    def __repr__(self) :
        return str(self._numerator) + "/" + str(self._denominator)
```

Checking Type

- To ensure that, Python provides the built-in `isinstance()` function that can be used to check the type of object referenced by a variable.
- For example, the constructor for the `Fraction` class requires two integers

```
class Fraction :
    def _ _init_ _(self, numerator, denominator) :
        if (not isinstance(numerator, int) or
            not isinstance(denominator, int)) :
           raise TypeError
              ("The numerator and denominator must be integers.")
```

Summary: Classes and Objects

- A class describes a set of objects with the same behavior
  - Every class has a public interface: a collection of methods through which the objects of the class can be manipulated
  - Encapsulation is the act of providing a public interface and hiding the implementation details
  - Encapsulation enables changes in the implementation without affecting users of a class

Summary: Variables and Methods

- An object's instance variables store the data required for executing its methods
- Each object of a class has its own set of instance variables
- An instance method can access the instance variables of the object on which it acts
- A private instance variable should only be accessed by the methods of its own class
- Class variables have a single copy of the variable shared among all of the instances of the class

Summary: Method Headers, Data

- Method Headers
  - You can use method headers and method comments to specify the public interface of a class
  - A mutator method changes the object on which it operates
  - An accessor method does not change the object on which it operates
- Data Representation
  - For each accessor method, an object must either store or compute the result
  - Commonly, there is more than one way of representing the data of an object, and you must make a choice
  - Be sure that your data representation supports method calls in any order

Summary: Constructors

- A constructor initializes the object's instance variables
- A constructor is invoked when an object is created
- The constructor is defined using the special method name: `_ _init_ _()`
- Default arguments can be used with a constructor to provide different ways of creating an object

Summary: Method Implementation

- The object on which a method is applied is automatically passed to the `self` parameter variable of the method
- In a method, you access instance variables through the `self` parameter variable

Summary: Testing Classes

- A unit test verifies that a class works correctly in isolation, outside a complete program
- To test a class, use an environment for interactive testing, or write a tester class to execute test instructions
- Determining the expected result in advance is an important part of testing

Summary: Object Tracing

- Object tracing is used to visualize object behavior
- Write the methods on the front of a card, and the instance variables on the back
- Update the values of the instance variables when a mutator method is called

Summary: Patterns for Classes

- An instance variable for the total is updated in methods that increase or decrease the total amount
- A counter that counts events is incremented in methods that correspond to the events
- An object can collect other objects in a list
- An object property can be accessed with a getter method and changed with a setter method
- If your object can have one of several states that affect the behavior, supply an instance variable for the current state

Summary: Patterns for Classes

- To model a moving object, you need to store and update its position

Summary: Object References

- An object reference specifies the location of an object
- Multiple object variables can contain references to the same object
- Use the `is` and `is not` operators to test whether two variables are aliases
- The `None` reference refers to no object

Summary: Defining Special Methods

- To use a standard operator with objects, define the corresponding special method
- Define the special `__repr__()` method to create a string representation of an object