Python Tutorial – Part 2: Objects and Classes

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Overview

1. Working with Objects and Classes
2. Data Hiding and Encapsulation
3. Relationships Among Classes
4. Inheritance Mechanisms
5. Composition of Object Models
6. Working with Groups of Objects
7. Spatial Data and Dataset Transformation (GeoPandas)
8. Case Study: GeoModeling Spatial Entities

Working with Objects and Classes

Working with Objects and Classes

Working with Objects and Classes:

- Collections of objects share similar traits (e.g., data, structure, behavior).
- Collections of objects will form relationships with other collections of objects.

Definition of a Class

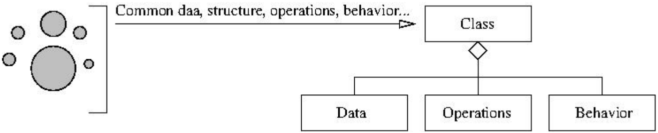
A class is a specification (or blueprint) of an object's structure and behavior.

Definition of an Object

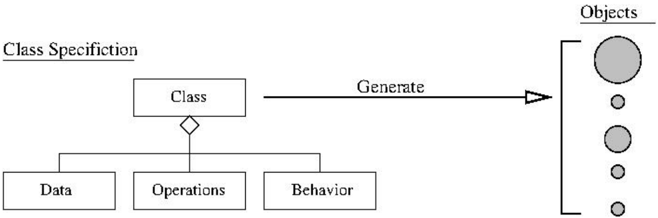
An object is an instance of a class.

Working with Objects and Classes

From Collections of Objects to Classes:



Generation of Objects from Class Specifications:



Working with Objects and Classes

Principles for Development of Reusable Code:

- **Inheritance:** Create new (specialized) classes from existing classes through mechanism of concept extension.
- **Encapsulation:** Hide some details of a class from other (external) classes.
- **Polymorphism:** Use common operation in different ways depending on details of data input.

Key Design Tasks

- Identify objects and their attributes and functions,
- Establish relationships among the objects,
- Implement and test the individual objects,
- Assemble and test the system.

Example 1. Working with Points

A Very Simple Class in Python

```
# =======================================================
# Point.py: Create point objects ...
#
# Modified by: Mark Austin                  October, 2020
# =======================================================

import math

class Point:

    def __init__(self, xCoord=0, yCoord=0):
        self.__xCoord = xCoord
        self.__yCoord = yCoord

    # compute distance between two points ...

    def distance(self, second):
        x_d = self.__xCoord - second.__xCoord
        y_d = self.__yCoord - second.__yCoord
        return (x_d**2 + y_d**2)**0.5

    # return string represention of object ...

    def __str__(self):
        return "( %6.2f, %6.2f ) " % ( self.__xCoord, self.__yCoord )
```

Example 1. Working with Points

Create and Print two Point Objects

```
    pt1 = Point( 0.0, 0.0 )
    pt2 = Point( 3.0, 4.0 )

    print("--- pt1 = %s ..." % (pt1) )
    print("--- pt2 = %s ..." % (pt2) )
```

Output:

```
--- pt1 = (   0.00,   0.00 )  ...
--- pt2 = (   3.00,   4.00 )  ...
```

Compute Distance between Two Points

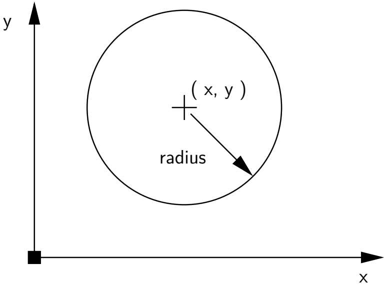
```
    distance = pt1.distance(pt2)
    print("--- Distance between pt1 and pt2 --> %.2f ..." % (distance) )
```

Output:

```
--- Distance between pt1 and pt2 --> 5.00 ...
```

Example 2. Working with Circles

A circle can be described by the `(x,y)` position of its center and by its `radius`.



There are numerous things we can do with circles:

- Compute their circumference, perimeter or area,
- Check if a point is inside a circle.

Example 2. Working with Circles

```
# =======================================================
# Circle.py: Simplified modeling of a circle ...
#
# Written by: Mark Austin                   October, 2020
# =======================================================

import math

class Circle:
  radius = 0
  area   = 0
  perimeter = 0

  def __init__(self, x, y, radius):
    self.radius    = radius
    self.area      = math.pi*radius*radius
    self.perimeter = 2.0*math.pi*radius
    self.x = x
    self.y = y

  # Set circle radius, recompute area and perimeter ...

  def setRadius(self, radius):
    self.radius = radius
    self.area   = math.pi*radius*radius
    self.perimeter = 2.0*math.pi*radius
```

Example 2. Working with Circles

```

  # Print details of circle ...

  def printCircle(self):
    print("--- Circle: (x,y) = (%.2f, %.2f): radius = %.2f: area = %.2f: perimeter = %.2
          % ( self.x, self.y, self.radius, self.area, self.perimeter ) )
```

Create and Print two Circle Objects

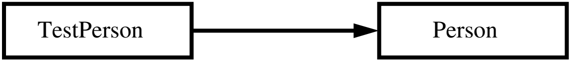
```
    x = Circle( 0.0, 0.0, 3.0 )
    y = Circle( 1.0, 2.0, 4.0 )
    x.printCircle()
    y.printCircle()
```

Output:

```
--- Circle: (x,y) = (0.00, 0.00): radius = 3.00: area = 28.27
--- Circle: (x,y) = (1.00, 2.00): radius = 4.00: area = 50.27
```

Example 3. Object Model of a Person

Part I: Program Architecture. The TestPerson will create objects of type Person.



Part II: Person Object Model:

```
# ======================================================
# Person.py: Simplified model of a person ...
#
# Written by: Mark Austin                  October, 2022
# ======================================================

class Person:
  age = 0
  ssn = 0

  def __init__(self, fname, lname):
    self.firstname = fname
    self.lastname  = lname

  def printname(self):
    print("--- Name: {:s}, {:s}".format( self.firstname, self.lastname) )
```

Example 3. Object Model of a Person

Part II: Person Object Model: (Continued) ...

```

  # Get first and last names ...

  def getFirstName(self):
    return self.firstname

  def getLastName(self):
    return self.lastname

  # Set/print age ...

  def setAge(self, age):
    self.age = age

  def printAge(self):
    print("--- Age = {:d} ".format(self.age) )

  # Set/print social security number ...

  def setSSN(self, ssn ):
    self.ssn = ssn

  def printSSN(self):
    print("--- Social Security No: {:d} ...".format(self.ssn) )
```

Example 3. Object Model of a Person

Part III: Person Test Program:

```
# =====================================================
# TestPerson.py: Test program for person objects ...
# =====================================================

from Person import Person

# main method ...

def main():
    print("--- Enter TestPerson.main()          ... ");
    print("--- ================================ ... ");

    # Exercise methods in class Person ...

    x = Person( "Angela", "Austin" )
    x.printname()

    print("--- First name: {:s} ".format( x.getFirstName() ) )
    print("--- Family name: {:s} ".format( x.getLastName() ) )

    # Initialize attribute values ..

    x.setAge(29)
    x.setSSN(123456789)

    # Print attribute values ..
```

Example 3. Test Program for Person Object Model

Part III: Person Test Program: (Continued) ...

```
    x.printAge()
    x.printSSN()

    print("--- =============================== ... ");
    print("--- Finished TestPerson.main()      ... ");

# call the main method ...

main()
```

Output:

```
--- Enter TestPerson.main()         ...
--- =============================== ...
--- Name: Angela, Austin
--- First name: Angela
--- Family name: Austin
--- Age = 29
--- Social Security No: 123456789
--- =============================== ...
--- Finished TestPerson.main()      ...
```

Example 3. Object Model of a Person

Part IV: Files before Program Execution:

```
-rw-r--r--  1 austin  staff   903 Feb 18 13:21 Person.py
-rw-r--r--  1 austin  staff   847 Feb 18 13:26 TestPerson.py
```

Part IV: Files after Program Execution:

```
-rw-r--r--  1 austin  staff   903 Feb 18 13:21 Person.py
-rw-r--r--  1 austin  staff   847 Feb 18 13:26 TestPerson.py
drwxr-xr-x  4 austin  staff   128 Feb 18 13:27 __pycache__

./__pycache__:
total 16
-rw-r--r--  1 austin  staff  1476 Feb 18 13:27 Person.cpython-37.pyc
```

Note: When TestPerson imports Person, python builds a compiled bytecode for Person (with .pyc extension).

Subsequent imports will be easier and faster.

Data Hiding and Encapsulation

Hiding Information

Data Hiding

Data Hiding is isolation of the client from a part of program implementation. Some objects in the module are kept internal, invisible, and inaccessible to the user.

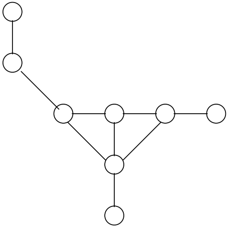
Principle of Information Hiding

The principle of information hiding states that information which is likely to change (e.g., over the lifetime of a software/systems package) should be hidden inside a module.

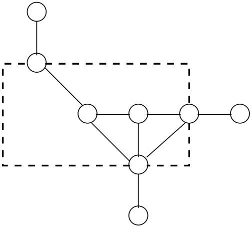
Key Advantages

- Prevents accidental linkage to incorrect data.
- It heightens the security against hackers that are unable to access confidential data.

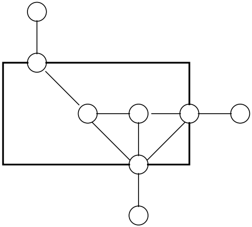
Data Hiding and Encapsulation



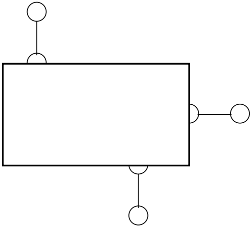
Unstructured Components



Aggregation



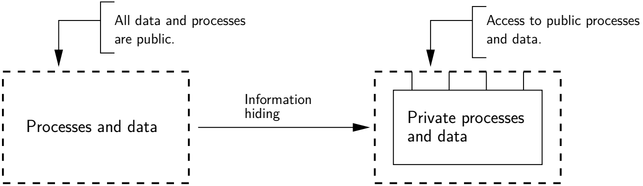
Designer's view of Aggregation



Encapsulation – User's view of Abstraction

Data Hiding and Encapsulation

Application. Process for Implementation of Information Hiding.


All data and processes are public.
Access to public processes and data.
Processes and data
Information hiding
Private processes and data

Data Hiding in Python (Private and Protected) ...

- Data hiding is implemented by using a double underscore before (prefix) the attribute name. Making an attribute private hides it from users.
- Use of a single underscore makes the variable/method protected. The variables/methods will be available to the class, and all of its subclasses.

Example 4. Revised Circle Object Model

Part I: Revised Circle Object Model

```
# ============================================================
# Circle.py: Implementation of circle model with encapsulation
# (hiding) of circle parameters and properties.
#
# Written by: Mark Austin                        October, 2020
# ============================================================

import math

class Circle:
  __radius = 0           # <-- private parameters ....
  __area   = 0
  __perimeter = 0

  def __init__(self, x, y, radius):
    self.__radius    = radius
    self.__area      = math.pi*radius*radius
    self.__perimeter = 2.0*math.pi*radius
    self.__x = x
    self.__y = y

  # Set circle coordinates ...

  def setX(self, x):
    self.__x = x
```

Example 4. Revised Circle Object Model

Part I: Revised Circle Object Model (Continued) ...

```
  def setY(self, y):
    self.__y = y

  # Set circle radius, recompute area and perimeter ...

  def setRadius(self, radius):
    self.__radius = radius
    self.__area   = math.pi*radius*radius
    self.__perimeter = 2.0*math.pi*radius

  # Get circle parameters ...

  def getX(self):
    return self.__x

  def getY(self):
    return self.__y

  def getRadius(self):
    return self.__radius

  def getArea(self):
    return self.__area

  def getPerimeter(self):
    return self.__perimeter
```

Example 4. Revised Circle Object Model

Part I: Revised Circle Object Model (Continued) ...

```
  # String represention of circle ...

  def __str__(self):
     return "--- Circle: (x,y) = (%.2f, %.2f): radius = %.2f: area = %.2f:
            perimeter = %.2f" % ( self.__x, self.__y, self.__radius,
            self.__area, self.__perimeter )
```

Part II: Test Program for Circle Object Model

```
# =======================================================
# TestCircles.py: Exercise circle objects.
#
# Written by: Mark Austin                   December 2022
# =======================================================

from Circle import Circle

# main method ...

def main():
    print("--- Enter TestCircles.main()         ... ");
    print("--- ================================ ... ");

    print("--- Part 1: Create and print circle ... ");

    x = Circle( 0.0, 0.0, 3.0 )
    print(x)
```

Example 4. Revised Circle Object Model

Part II: Test Program for Circle Object Model (Continued) ...

```
    print("--- =============================== ... ");
    print("--- Finished TestCircles.main()     ... ");

# call the main method ...

main()
```

Part III: Program Output

```
--- Enter TestCircles.main()        ...
--- =============================== ...
--- Circle: (x,y) = (0.00, 0.00): radius = 3.00: area = 28.27
--- =============================== ...
--- Finished TestCircles.main()     ...
```

Relationships Among Classes

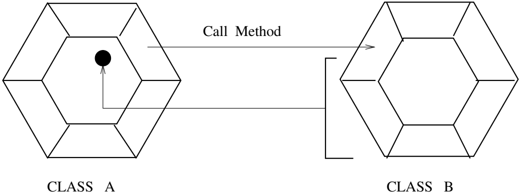
Relationships Among Classes

Motivation

- Classes and objects by themselves are not enough to describe the structure of a system.
- We also need to express relationships among classes.
- Object-oriented software packages are assembled from collections of classes and class-hierarchies that are related in three fundamental ways.

Relationships Among Classes

1. **Use:** Class A uses Class B (method call).



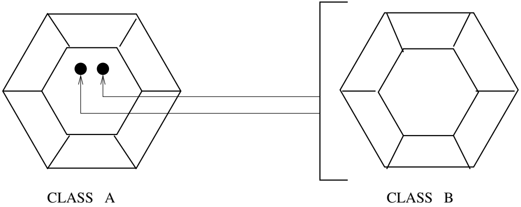
Class `A` uses Class `B` if a method in `A` calls a method in an object of type `B`.

Example

```
    import math

    dAngle = math.sin ( math.PI / 3.0 );
```

Relationships Among Classes

2. Containment (Has a): Class A contains a reference to Class B.



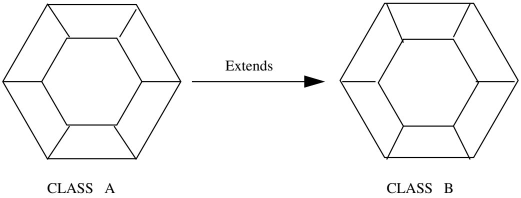
Clearly, containment is a special case of use (i.e., see Item 1.).

Example

```
class LineSegment
   self.start = Point() ...
   self.end   = Point() ...
```

Relationships Among Classes

3. Inheritance (Is a): In everyday life, we think of inheritance as something that is received from a predecessor or past generation. Here, Class B inherits the data and methods (extends) from Class A.



Two Examples from Python

```
class ColoredCircle (Circle) ....
class Student (Person) ....
```

Inheritance Mechanisms

Inheritance Mechanisms

Inheritance Structures

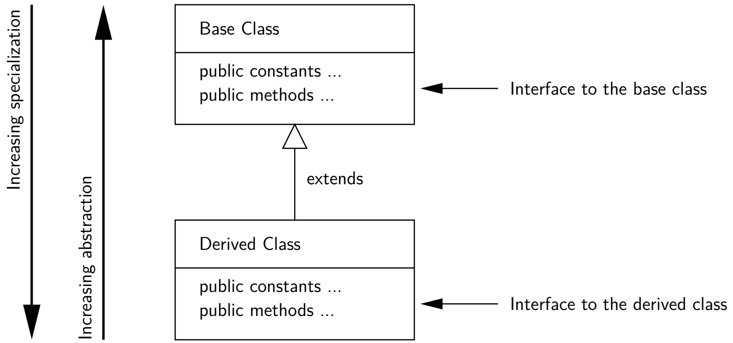
Inheritance structures allow you to capture common characteristics in one model artifact and permit other artifacts to inherit and possibly specialize them. Class hierarchies are explicitly designed for customization through extension.

In this approach to development:

- Forces us to identify and separate the common elements of a system from those aspects that are different/distinct.
- Commonalities are captured in a super-class and inherited and specialized by the sub-classes.
- Inherited features may be overridden with extra features designed to deal with exceptions.

Base and Derived Classes

Goal: Avoid duplication and redundancy of data in a problem specification.



Base and Derived Classes

Points to note:

- A class in the upper hierarchy is called a superclass (or base, parent class).
- A class in the lower hierarchy is called a subclass (or derived, child, extended class).
- The classes in the lower hierarchy inherit all the variables (static attributes) and methods (dynamic behaviors) from the higher-level classes.

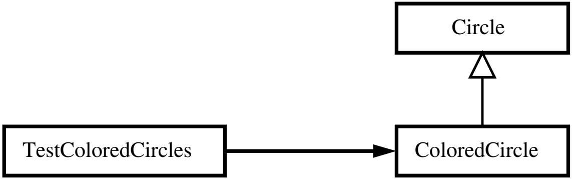
Base and Derived Classes

Python Syntax:

```
# ------------------------------------
# Base Class ...
# ------------------------------------

class BaseClass:

      # Constructor of Base Class

      # Base class variables and methods ...

# ------------------------------------
# Derived class extends Base Class ...
# ------------------------------------

class DerivedClass( BaseClass ):

      # Constructor of Derived Class

      # Derived class variables and methods ...
```

Example 5. Model Colored Circles by Extending Circle

Part I: Program Architecture. The TestCircle program will create objects of type ColoredCircle.



Circle Attributes:

- _x, _y, _radius, _area, _perimeter.

ColoredCircle Attributes:

- _color.

Example 5. Model Colored Circles by Extending Circle

Part IIa: Circle Object Model (with Protected Variables)

```python
# ===========================================================
# Circle.py: Implementation of circle model with protection of
# circle parameters and methods.
#
# Written by: Mark Austin                        October, 2020
# ===========================================================

import math

class Circle:
  _radius = 0
  _area   = 0
  _perimeter = 0

  def __init__(self, x, y, radius):
    self._radius    = radius
    self._area      = math.pi*radius*radius
    self._perimeter = 2.0*math.pi*radius
    self._x = x
    self._y = y

  # Set circle coordinates ...

  def setX(self, x):
    self._x = x

  def setY(self, y):
```

Example 5. Model Colored Circles by Extending Circle

Part IIa: Circle Object Model (Continued) ...

```
    self._y = y

  # Set circle radius, recompute area and perimeter ...

  def setRadius(self, radius):
    self._radius = radius
    self._area    = math.pi*radius*radius
    self._perimeter = 2.0*math.pi*radius

  # Get circle parameters ...

  def getX(self):
    return self._x

  def getY(self):
    return self._y

  def getRadius(self):
    return self._radius

  def getArea(self):
    return self._area

  def getPerimeter(self):
    return self._perimeter
```

Example 5. Model Colored Circles by Extending Circle

Part IIa: Circle Object Model (Continued) ...

```
    # String represention of circle ...

    def __str__(self):
       return "--- Circle: (x,y) = (%.2f, %.2f): radius = %.2f: area = %.2f: perimeter = %
              self._x, self._y, self._radius, self._area, self._perimeter )
```

Example 5. Model Colored Circles by Extending Circle

Part IIb: Colored Circle Object Model

```
# =========================================================
# ColoredCircle.py: Extend circle to create coloredcircles.
#
# Written by: Mark Austin                     October, 2022
# =========================================================

from Circle import Circle

class ColoredCircle(Circle):
  def __init__(self, x, y, radius, color):
    Circle.__init__(self, x, y, radius)
    self._color = color

  # Set/get color ...

  def setColor(self, color):
    self._color = color

  def getColor(self):
    return self._color

  # String representation of colored circle ...

  def __str__(self):
    return "--- ColoredCircle: (x,y) = (%4.1f, %4.1f): radius = %5.2f: area = %6.2f: col
            self._x, self._y, self._radius, self._area, self._color )
```

Example 5. Model Colored Circles by Extending Circle

Part II: Colored Circle Test Program

```
# =======================================================
# TestColoredCircles.py: Exercise colored circle objects.
#
# Written by: Mark Austin                   December 2022
# =======================================================

from Circle import Circle
from ColoredCircle import ColoredCircle

# main method ...

def main():
    print("--- Enter TestCircles.main()        ... ");
    print("--- =============================== ... ");

    print("--- Part 1: Create and print circle ... ");

    x = Circle( 0.0, 0.0, 3.0 )
    print(x)

    print("--- Part 2: Create and print colored circle ... ");

    y = ColoredCircle( 0.0, 0.0, 0.0, "blue" )
    print(y)
    y.setRadius(1.0)
    print(y)
    y.setRadius(2.0)
```

Example 5. Model Colored Circles by Extending Circle

Part II: Colored Circle Test Program (Continued) ...

```
    print(y)

    print("--- Part 3: Change coordinates and color ... ");

    y.setX( 1.0 )
    y.setY( 1.0 )
    y.setColor("red" )
    y.setRadius(3.0)

    print(y)

    print("--- =============================== ... ");
    print("--- Finished TestCircles.main()      ... ");

# call the main method ...

main()
```

Example 5. Model Colored Circles by Extending Circle

Part III: Abbreviated Output:

```
--- Enter TestCircles.main()        ...
--- =============================== ...
--- Part 1: Create and print circle ...
--- Circle: (x,y) = (0.00, 0.00): radius = 3.00: area = 28.27: perimeter = 18.85
--- Part 2: Create and print colored circle ...
--- ColoredCircle: (x,y) = ( 0.0,  0.0): radius =  0.00: area =  0.00: color = blue
--- ColoredCircle: (x,y) = ( 0.0,  0.0): radius =  1.00: area =  3.14: color = blue
--- ColoredCircle: (x,y) = ( 0.0,  0.0): radius =  2.00: area = 12.57: color = blue
--- Part 3: Change coordinates and color ...
--- ColoredCircle: (x,y) = ( 1.0,  1.0): radius =  3.00: area = 28.27: color = red
--- =============================== ...
--- Finished TestCircles.main()     ...
```

Source Code: See: python-code.d/inheritance/

Example 5. Model Colored Circles by Extending Circle

Part IV: Files before Program Execution:

```
-rw-r--r--  1 austin  staff   903 Feb 18 13:21 Circle.py
-rw-r--r--  1 austin  staff   903 Feb 18 13:21 ColoredCircle.py
-rw-r--r--  1 austin  staff   847 Feb 18 13:26 TestColoredCircles.py
```

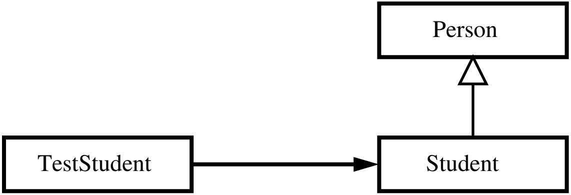
Part IV: Files after Program Execution:

```
-rw-r--r--  1 austin  staff   903 Feb 18 13:21 Circle.py
-rw-r--r--  1 austin  staff   903 Feb 18 13:21 ColoredCircle.py
-rw-r--r--  1 austin  staff   847 Feb 18 13:26 TestColoredCircles.py
drwxr-xr-x  4 austin  staff   128 Feb 18 13:27 __pycache__

./__pycache__:
total 16
-rw-r--r--  1 austin  staff  1476 Feb 18 13:27 Circle.cpython-37.pyc
-rw-r--r--  1 austin  staff  1476 Feb 18 13:27 ColoredCircle.cpython-37.pyc
```

Note: Python builds compiled bytecodes for Circle and ColoredCircle (with .pyc extension).

Example 6. Student is an Extension of Person

Part I: Program Architecture. The TestStudent program will create objects of type Student.



Person Attributes:

- _firstname, _lastname, _age (age), _ssn (social security), _dob (date of birth).

Student Attributes:

- _gpa (grade point average).

Example 6. Student is an Extension of Person

Part IIa: Person Object Model (with Protected Variables)

```
# ==================================================================
# Person.py: Simple model of a Person. The scope of variables
# _age, _ssn, and _dob are protected to Person and all subclasses.
#
# Written by: Mark Austin                              November 2022
# ==================================================================

from datetime import date

class Person:
   _age = 0   # <-- age ...
   _ssn = 0   # <-- social security number ...
   _dob = 0   # <-- date of birth ...

   # Constructor method ...

   def __init__(self, fname, lname, dob ):
     self._firstname = fname
     self._lastname  = lname
     self._dob       = dob
     self._age       = self.calculateAge()

   # Get first and last names ...

   def getFirstName(self):
     return self._firstname
```

Example 6. Student is an Extension of Person

Part IIa: Person Object Model (Continued) ...

```

    def getLastName(self):
      return self._lastname

    # Set/get date of birth ...

    def setDob(self, dob):
      self._dob = dob

    def getDob(self, dob):
      return self._dob

    # Calculate age ...

    def calculateAge(self):
       today = date.today()
       age   = today.year - self._dob.year - ((today.month, today.day) < (self._dob.month
       return age

    # Set/get/print age ...

    def setAge(self, age):
      self._age = age

    def getAge(self):
      return self._age
```

Example 6. Student is an Extension of Person

Part IIa: Person Object Model (Continued) ...

```

  # Set/get/print social security number ...

  def setSSN(self, ssn ):
    self._ssn = ssn

  def getSSN(self):
    return self._ssn

  # return string represention of object ...

  def __str__(self):
      return "Person: {:6.2f} {:6.2f}: age = {:f} ".format( self._firstname,
                                                            self._lastname,
                                                            self._age )
```

Example 6. Student is an Extension of Person

Part Ib: Student Object Model

```python
# =============================================================
# Student.py: A Student is a specialization of Person ...
# =============================================================

from Person import Person

class Student(Person):
   _gpa = 0

   # Parameterized constructor ...

   def __init__(self, fname, lname, dob, year):
     Person.__init__(self, fname, lname, dob)
     self._graduationyear = year

   # Set/get gpa ...

   def setGpa(self, gpa):
     self._gpa = gpa

   def getGpa(self):
     return self._gpa
```

Example 6. Student is an Extension of Person

Part Ib: Student Object Model

```
   # Boolean to confirm person is a student ...

   def isStudent(self):
      return True

   # Assemble string represention of student ...

   def __str__(self):
      studentinfo = [];
      studentinfo.append("\n");
      studentinfo.append("--- Student: {:s} {:s} ...  \n".format( self._firstname,
                                                                  self._lastname));
      studentinfo.append("--- ------------------------------------------------- \n");
      studentinfo.append("---   Gpa = {:6.2f} ... \n".format( self._gpa));
      studentinfo.append("---   Age = {:6d} ... \n".format( self._age));
      studentinfo.append("---   Graduation year = {:d} ... \n".format(
                                                           self._graduationyear ));
      studentinfo.append("--- ------------------------------------------------- ");
      return "".join(studentinfo);
```

Example 6. Student is an Extension of Person

Part II: Student Test Program

```
# =====================================================
# TestStudent.py: Exercise methods in Student class ...
#
# Written by: Mark Austin                 November 2022
# =====================================================

from Student import Student
from datetime import date

# main method ...

def main():
    print("--- Enter TestStudents.main()             ... ");
    print("--- ===================================== ... ");

    print("--- Part 1: Create student Angela Austin ...")

    y = Student( "Angela", "Austin", date(2002,3,2) ,2023)
    y.setGpa(3.5)
    y.setSSN(1234)

    print("--- Part 2: Retrieve student parameters ...")

    print("---  First Name: {:s}".format( y.getFirstName() ) )
    print("---  Last Name: {:s}".format( y.getLastName() ) )
    print("---  Age = {:d}".format( y.getAge() ) )
    print("---  Social Security Number = {:d}".format( y.getSSN() ) )
```

Example 6. Student is an Extension of Person

Part II: Student Test Program (Continued) ...

```
    print("---  Is student: {:s}".format( str( y.isStudent()) ) )

    print("--- Part 3: Assemble string representation of student ...")

    print( y.__str__() )

    print("--- ======================================= ... ");
    print("--- Finished TestStudents.main()             ... ");

# call the main method ...

main()
```

Example 6. Student is an Extension of Person

Part III: Abbreviated Output:

```
--- Part 1: Create student Angela Austin ...
--- Part 2: Retrieve student parameters ...
---
---  First Name: Angela
---  Last Name: Austin
---  Age = 20
---  Social Security Number = 1234
---  Is student: True
---
--- Part 3: Assemble string representation of student ...
---
--- Student: Angela Austin ...
--- -------------------------------------------------
---   Gpa =   3.50 ...
---   Age =     20 ...
---   Graduation year = 2023 ...
--- -------------------------------------------------
```

Source Code: See: python-code.d/inheritance/

Example 6. Student is an Extension of Person

Part IV: Files before Program Execution:

```
-rw-r--r--  1 austin  staff   903 Feb 18 13:21 Person.py
-rw-r--r--  1 austin  staff   903 Feb 18 13:21 Student.py
-rw-r--r--  1 austin  staff   847 Feb 18 13:26 TestStudents.py
```

Part IV: Files after Program Execution:

```
-rw-r--r--  1 austin  staff   903 Feb 18 13:21 Person.py
-rw-r--r--  1 austin  staff   903 Feb 18 13:21 Student.py
-rw-r--r--  1 austin  staff   847 Feb 18 13:26 TestStudents.py
drwxr-xr-x  4 austin  staff   128 Feb 18 13:27 __pycache__

./__pycache__:
total 16
-rw-r--r--  1 austin  staff  1476 Feb 18 13:27 Person.cpython-37.pyc
-rw-r--r--  1 austin  staff  1476 Feb 18 13:27 Student.cpython-37.pyc
```

Note: Python builds compiled bytecodes for Student and Person (with .pyc extension).

Mutiple Inheritance Mechanisms

Multiple Inheritance Structures

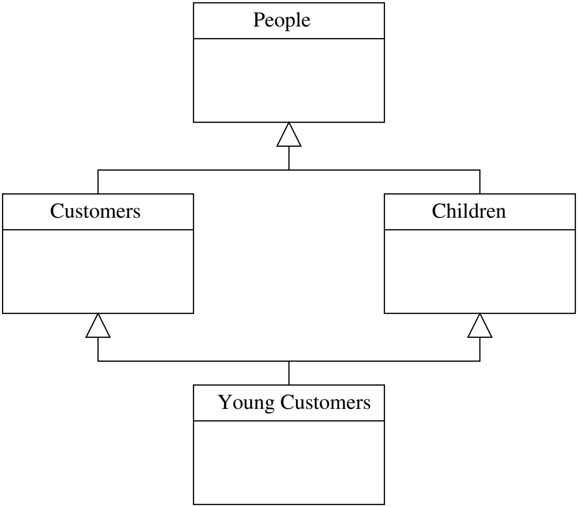
- In a multiple inheritance structure, a class can inherit properties from multiple parents.
- The downside is that properties and/or operations may be partially or fully contradictory.

Example

- People is a generalization of Children and Customers.
- Young customers inherits properties from Customers and Children.

Note. Python supports use of multiple inheritance. Java explicitly prevents multiple inheritance – instead, it allows classes to have multiple interfaces.

Mutiple Inheritance Mechanisms



Mutiple Inheritance Mechanisms

Python Syntax:

```
class People:

      # People constructor ...
      # People variables, and methods ...

class Customers (People):

      # Customers constructor ...
      # Customers variables, and methods ...

class Children (People):

      # Children constructor ...
      # Children variables, and methods ...

class YoungCustomers( Customers, Children ):

      # YoungCustomer constructor ...
      # YoungCustomer variables, and methods ...
```

Composition of Object Models

Composition of Object Models

Definition

Composition is known as is a part of or is a relationship.

The member object is a part of the containing class and the member object cannot survive or exist outside the enclosing or containing class or doesn't have a meaning after the lifetime of the enclosing object.

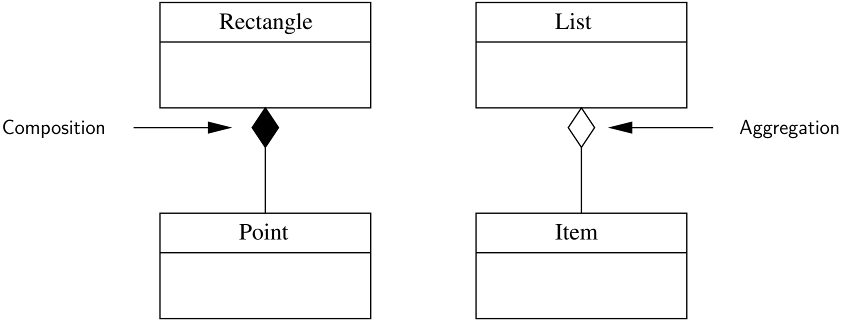
Is it Aggregation or Composition?

- Ask the question: if the part moves, can one deduce that the whole moves with it in normal circumstances?

Example: A car is composition of wheels and an engine. If you drive the car to work, hopefully the wheels go too!

Composition of Object Models

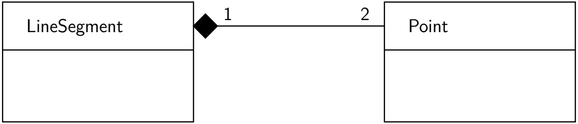
Notation for Aggregation and Composition



Recall: Aggregation is all about grouping of things ...

Example 7. Modeling Line Segments

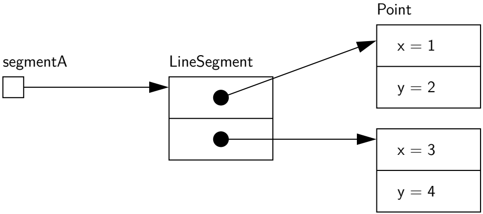
Model Composition



Creating a line segment object with:

```
segmentA = LineSegment( 1, 2, 3, 4 );
```

should give a layout of memory:



Example 7. Modeling Line Segments

Part I: Line Segment Object Model

```
# ====================================================================
# LineSegment.py: Line segments are defined by end points (x1, y1) and
# (x2, y2). Compute length and angle of the line segment in radians.
#
# Written by: Mark Austin                                October, 2022
# ====================================================================

import math

from Point import Point

class LineSegment:
  __length = 0
  __angle  = 0

  def __init__(self, x1, y1, x2, y2 ):
    self.__pt1 = Point(x1,y1)               # <-- Object composition ...
    self.__pt2 = Point(x2,y2)               # <-- Object composition ...
    self.__length = self.__pt1.distance(self.__pt2)
    self.__angle  = self.getAngle()

  # Compute angle (radians) for coordinates in four quadrants ....

  def getAngle(self):
     dX = self.__pt2.get_xCoord() - self.__pt1.get_xCoord();
     dY = self.__pt2.get_yCoord() - self.__pt1.get_yCoord();
```

Example 7. Modeling Line Segments

Part I: Line Segment Object Model (Continued) ...

```

      if dY >  0.0 and dX == 0.0:
         angle = math.pi/2.0
      if dY >= 0.0 and dX > 0.0:
         angle = math.atan( dY/dX )
      if dY >= 0.0 and dX < 0.0:
         angle = math.pi + math.atan( dY/dX )
      if dY < 0.0 and dX < 0.0:
         angle = math.pi + math.atan( dY/dX )
      if dY < 0.0 and dX >= 0.0:
         angle = 2*math.pi + math.atan( dY/dX )

      return angle

   # String represention of line segment ...

   def __str__(self):
      x1 = self.__pt1.get_xCoord();
      y1 = self.__pt1.get_yCoord();
      x2 = self.__pt2.get_xCoord();
      y2 = self.__pt2.get_yCoord();
      return "--- LineSegment: (x1,y1) = (%5.2f, %5.2f), (x2,y2) = (%5.2f, %5.2f),
                  angle = %.2f, length = %.2f" % ( x1, y1, x2, y2, self.__angle, self.__l
```

Example 7. Modeling Line Segments

Part II: Line Segment Test Program

```
# =====================================================
# TestLineSegment.py: Exercise line segment class ...
# =====================================================

from LineSegment import LineSegment

# main method ...

def main():
    print("--- Enter TestLineSegment.main()    ... ");
    print("--- =============================== ... ");

    print("--- Part 1: Create test line segment ... ");

    segmentA = LineSegment( 1.0, 2.0,  3.0,  4.0 )
    print(segmentA)

    print("--- Part 2: Sequence of line segments ... ");

    a = LineSegment( 0.0, 0.0,  3.0,  0.0 )
    print(a)
    b = LineSegment( 0.0, 0.0,  3.0,  3.0 )
    print(b)
    c = LineSegment( 0.0, 0.0,  0.0,  3.0 )
    print(c)
    d = LineSegment( 0.0, 0.0, -3.0,  3.0 )
    print(d)
```

Example 7. Modeling Line Segments

Part II: Line Segment Test Program (Continued) ...

```
    e = LineSegment( 0.0, 0.0, -3.0,  0.0 )
    print(e)

    print("--- =============================== ... ");
    print("--- Finished TestLineSegment.main() ... ");

# call the main method ...

main()
```

Part III: Abbreviated Program Output:

```
--- Part 1: Create test line segment ...
--- LineSegment: (x1,y1) = ( 1.00,  2.00), (x2,y2) = ( 3.00,  4.00), angle = 0.79, length = 2.83
--- Part 2: Sequence of line segments ...
--- LineSegment: (x1,y1) = ( 0.00,  0.00), (x2,y2) = ( 3.00,  0.00), angle = 0.00, length = 3.00
--- LineSegment: (x1,y1) = ( 0.00,  0.00), (x2,y2) = ( 3.00,  3.00), angle = 0.79, length = 4.24
--- LineSegment: (x1,y1) = ( 0.00,  0.00), (x2,y2) = ( 0.00,  3.00), angle = 1.57, length = 3.00
--- LineSegment: (x1,y1) = ( 0.00,  0.00), (x2,y2) = (-3.00,  3.00), angle = 2.36, length = 4.24
--- LineSegment: (x1,y1) = ( 0.00,  0.00), (x2,y2) = (-3.00,  0.00), angle = 3.14, length = 3.00
```

Source Code: See: python-code.d/classes/

Working with Groups of Objects

Pathway From Objects to Groups of Objects

Data Structures

Now that we know how to create objects, the next subject is how to organize collections of objects so that they are easy to store, easy to find, and easy to modify?

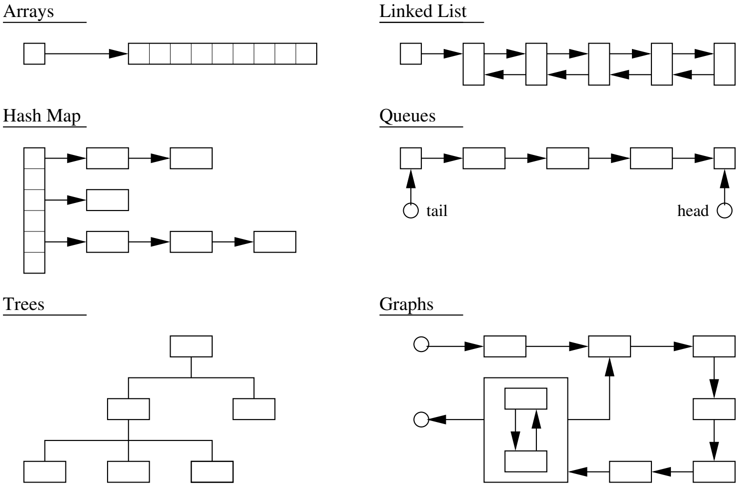
Approach: Two-step procedure:

- Choose an appropriate mathematical formalism.
- Develop software to support each formalism.

As a starting point, of objects can be organized into:

- Arrays
- Linked lists and queues (lists in Python).
- HashMaps (dictionaries in Python).
- Trees and Graphs.

Memory Layout: Arrays, Lists, Queues, Trees, and Graphs



Arrays

Linked List

Hash Map

Queues

Trees

Graphs

Linear and Nonlinear Data Structures

Linear Data Structure:

- Items are arranged in a linear fashion.
- Simple to implement.

Examples:

- **Array:** Sequential arrangement of data elements paired with the index of the data element.
- **Linked List:** Each data element contains a link to another element along with the data present in it.
- **Stack:** LIFO (last in First Out) or FILO (First in Last Out).
- **Queue:** Similar to Stack, but the order of operation is only FIFO (First In First Out).

Linear and Nonlinear Data Structures

Nonlinear Data Structure:

- Items are not ordered in any particular way.
- Often, items are often organized into hierarchies.

Examples:

- **Binary Tree:** Each data element can be connected to maximum two other data elements and it starts with a root node.
- **Hash Table:** Retrieves values using keys rather than index from a data element.
- **Graph:** Arrangement of vertices and nodes where some of the nodes are connected to each other through links.

Python Builtin Data Structures

Lists:

- Lists are used to store multiple items in a single variable.
- A list may store multiple types (heterogeneous) of elements.

Dictionary:

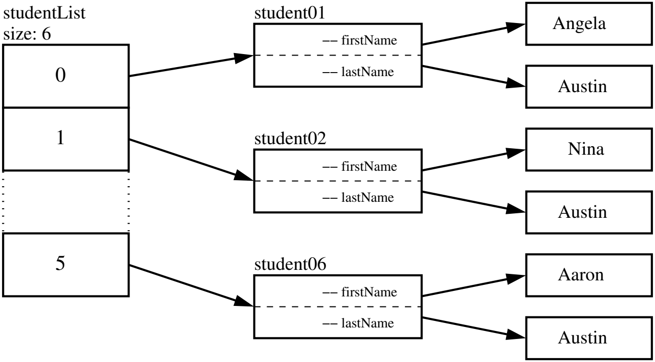
- Dictionaries store data values as key:value pairs.
- As of Python 3.7, a dictionary is a collection which is ordered, changeable and do not allow duplicates.

Set:

- Sets store multiple items in a single variable.
- A set is a collection which is unordered, unchangeable (but you can remove items and add new items) and unindexed.

Example 8: Create List of Student Objects

Part I: Program Architecture



Assemble list of six students. Sort and print by name and gpa.

Example 8: Create List of Student Objects

Part II: Assemble Student Objects ...

```
# ====================================================================
# TestStudents02.py: Assemble list of students ...
#
# Written by: Mark Austin                                February 2023
# ====================================================================

from Student import Student
from datetime import date

# main method ...

def main():
    print("--- Enter TestStudents02.main()                         ... ");
    print("--- =================================================== ... ");

    print("--- ")
    print("--- Part 1: Create student objects ...")

    student01 = Student( "Angela", "Austin", date(2002, 3, 2), 2023)
    student01.setGpa(3.5), student01.setSSN(1234)

    student02 = Student( "Nina", "Austin", date(2001, 4, 12), 2025)
    student02.setGpa(3.2), student02.setSSN(2134)

    student03 = Student( "David", "Austin", date(2000, 6, 8), 2025)
    student03.setGpa(2.9), student03.setSSN(2143)
```

Example 8: Create List of Student Objects

Part II: Assemble Student Objects ...

```

    student04 = Student( "Marie", "Austin", date(2005, 8, 5), 2026)
    student04.setGpa(3.9), student04.setSSN(1243)

    student05 = Student( "Albert", "Austin", date(1999, 10, 20), 2026)
    student05.setGpa(3.8), student05.setSSN(3124)

    student06 = Student( "Aaron", "Austin", date(2002, 12, 2), 2026)
    student06.setGpa(4.0), student06.setSSN(1131)

    print("--- ")
    print("--- Part 2: String description of student parameters ...")

    print( student01.__str__() )
    print( student02.__str__() )
    print( student03.__str__() )
    print( student04.__str__() )
    print( student05.__str__() )
    print( student06.__str__() )

    print("--- ")
    print("--- Part 3: Add students to list ... ")

    studentList = [];
    studentList.append(student01)
    studentList.append(student02)
    studentList.append(student03)
```

Example 8: Create List of Student Objects

Part II: Assemble Student Objects ...

```
studentList.append(student04)
studentList.append(student05)
studentList.append(student06)

print("--- ")
print("--- Part 4: Print contents of list ... ")

i = 0
for student in studentList:
   print ("---   list01[{:d}]: {:6s} --> {:.2f} ...".format( i, student.getFirstName
   i = i + 1

print("--- ")
print("--- Part 5: Sort list items by first name ... ")

sort_values = sorted( studentList , key = lambda x: x._firstname )

i = 0
for student in sort_values:
   print ("---   list01[{:d}]: {:6s} --> {:.2f} ...".format( i, student.getFirstName
   i = i + 1

print("--- ")
print("--- Part 6: Sort list items by gpa ... ")

sort_values = sorted( studentList , key = lambda x: x._gpa )

i = 0
```

Example 8: Create List of Student Objects

Part II: Assemble Student Objects ...

```
    for student in sort_values:
       print ("---   list01[{:d}]: {:6s} --> {:.2f} ...".format( i, student.getFirstName
       i = i + 1

    print("--- =================================================== ... ");
    print("--- Finished TestStudents02.main()                      ... ");

# call the main method ...

main()
```

Example 8: Create List of Student Objects

Part III: Abbreviated Output:

```
--- Enter TestStudents02.main()                         ...
--- =================================================== ...
--- Part 1: Create student objects ...
--- Part 2: String description of student parameters ...

--- Student: Angela Austin ...
--- -------------------------------------------------
---   Gpa = 3.50, Age = 20, Graduation year = 2023 ..
--- -------------------------------------------------

--- Student: Nina Austin ...
--- -------------------------------------------------
---   Gpa = 3.20, Age = 21, Graduation year = 2025 ..
--- -------------------------------------------------

--- Student: David Austin ...
--- -------------------------------------------------
---   Gpa = 2.90, Age = 22, Graduation year = 2025 ..
--- -------------------------------------------------
```

Example 8: Create List of Student Objects

Part III: Abbreviated Output: (Continued) ...

```
--- Student: Marie Austin ...
--- -------------------------------------------------
---   Gpa = 3.90, Age = 17, Graduation year = 2026 ..
--- -------------------------------------------------

--- Student: Albert Austin ...
--- -------------------------------------------------
---   Gpa = 3.80, Age = 23, Graduation year = 2026 ..
--- -------------------------------------------------

--- Student: Aaron Austin ...
--- -------------------------------------------------
---   Gpa = 4.00, Age = 20, Graduation year = 2026 ..
--- -------------------------------------------------

--- Part 4: Print contents of list ...
---
---   list01[0]: Angela --> 3.50 ...
---   list01[1]: Nina   --> 3.20 ...
---   list01[2]: David  --> 2.90 ...
```

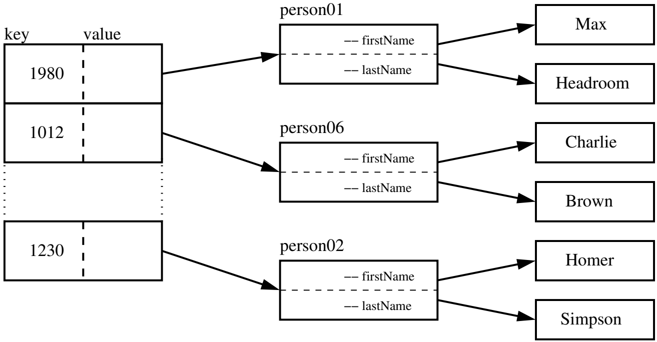
Example 8: Create List of Student Objects

Part III: Abbreviated Output: (Continued) ...

```
---   list01[3]: Marie  --> 3.90 ...
---   list01[4]: Albert --> 3.80 ...
---   list01[5]: Aaron  --> 4.00 ...
---
--- Part 5: Sort list items by first name ...
---   list01[0]: Aaron  --> 4.00 ...
---   list01[1]: Albert --> 3.80 ...
---   list01[2]: Angela --> 3.50 ...
---   list01[3]: David  --> 2.90 ...
---   list01[4]: Marie  --> 3.90 ...
---   list01[5]: Nina   --> 3.20 ...
---
--- Part 6: Sort list items by gpa ...
---   list01[0]: David  --> 2.90 ...
---   list01[1]: Nina   --> 3.20 ...
---   list01[2]: Angela --> 3.50 ...
---   list01[3]: Albert --> 3.80 ...
---   list01[4]: Marie  --> 3.90 ...
---   list01[5]: Aaron  --> 4.00 ...
```

Example 9: Dictionary of Fictional Characters

Part I: Program Architecture



Assemble dictionary of six cartoon characters (key = SSN, value = reference to object). Convert dictionary to list, then sort by age.

Example 9: Dictionary of Fictional Characters

Part II: Dictionary of Fictional Characters

```
# ===============================================================
# TestDictionary03.py: Create dictionary of objects ...
#
# Last Modified:                                    February 2023
# ===============================================================

from Person import Person

# main method ...

def main():
    print("--- Enter TestDictionary03.main()    ... ");
    print("--- ======================================== ... ");

    # Create cartoon characters ...

    print ("--- Part 01: Create cartoon character objects ...")

    person01 = Person( "Max", "Headroom" )
    person01.setAge(42)
    person01.setSSN(1980)

    person02 = Person( "Homer", "Simpson" )
    person02.setAge(55)
    person02.setSSN(1230)
```

Example 9: Dictionary of Fictional Characters

Part II: Dictionary of Fictional Characters:

```
    person03 = Person( "Bart", "Simpson" )
    person03.setAge(35)
    person03.setSSN(1231)

    person04 = Person( "Yogi", "Bear" )
    person04.setAge(65)
    person04.setSSN(1111)

    person05 = Person( "Charlie", "Brown" )
    person05.setAge(72)
    person05.setSSN(1012)

    print ("--- ")
    print ("--- Part 02: Print sample objects ...")
    print ("--- ")

    print("--- person01 --> {:s} ...".format(person01.__str__() ))
    print("--- person05 --> {:s} ...".format(person05.__str__() ))

    print ("--- ")
    print ("--- Part 03: Assemble dictionary of cartoon characters ...")

    cartoon = {}
    cartoon[ person01.getSSN() ] = person01
    cartoon[ person02.getSSN() ] = person02
    cartoon[ person03.getSSN() ] = person03
    cartoon[ person03.getSSN() ] = person03
```

Example 9: Dictionary of Fictional Characters

Part II: Dictionary of Fictional Characters:

```
    cartoon[ person04.getSSN() ] = person04
    cartoon[ person05.getSSN() ] = person05

    print ("--- ")
    print ("--- Part 04: Retrieve items from dictionary ...")
    print ("--- ")

    key = 1980
    personItem = cartoon.get(key)
    print("--- key = {:d} --> {:s} ...".format( key, personItem.__str__() ) )

    key = 1230
    personItem = cartoon.get(key)
    print("--- key = {:d} --> {:s} ...".format( key, personItem.__str__() ) )

    key = 1231
    personItem = cartoon.get(key)
    print("--- key = {:d} --> {:s} ...".format( key, personItem.__str__() ) )

    key = 1111
    personItem = cartoon.get(key)
    print("--- key = {:d} --> {:s} ...".format( key, personItem.__str__() ) )

    key = 1012
    personItem = cartoon.get(key)
    print("--- key = {:d} --> {:s} ...".format( key, personItem.__str__() ) )
```

Example 9: Dictionary of Fictional Characters

Part II: Dictionary of Fictional Characters:

```
    print ("--- ")
    print ("--- Part 04: Convert dictionary to list ...")

    keysList = list( cartoon.keys() )
    cartoonlist = [];
    for person in keysList:
        cartoonlist.append( cartoon.get(person) )

    print ("--- ")
    print ("--- Part 05: Sort list of cartoon items by age ...")
    print ("--- ")

    sorted_items = sorted( cartoonlist )

    i = 1
    for person in sorted_items:
        print ("---   person[%d]: %s --> %s ..." %( i, person.getFirstName(), person.getA
        i = i + 1

    print("--- ======================================== ... ");
    print("--- Leave TestDictionnary03.main()           ... ");

# call the main method ...

main()
```

Example 9: Dictionary of Fictional Characters

Part III: Abbreviated Output:

```
--- Enter TestDictionary03.main()    ...
--- ======================================== ...
--- Part 01: Create cartoon character objects ...
---
--- Part 02: Print sample objects ...
---
--- person01 --> Person: Max Headroom: age = 42.00  ...
--- person05 --> Person: Charlie Brown: age = 72.00  ...
---
--- Part 03: Assemble dictionary of cartoon characters ...
---
--- Part 04: Retrieve items from dictionary ...
---
--- key = 1980 --> Person: Max Headroom: age = 42.00  ...
--- key = 1230 --> Person: Homer Simpson: age = 55.00  ...
--- key = 1231 --> Person: Bart Simpson: age = 35.00  ...
--- key = 1111 --> Person: Yogi Bear: age = 65.00  ...
--- key = 1012 --> Person: Charlie Brown: age = 72.00  ...
```

Example 9: Dictionary of Fictional Characters

Part III: Abbreviated Output: (Continued) ...

```
--- Part 05: Convert dictionary to list ...
---
--- Part 06: Sort list of cartoon items by age ...
---
---   person[1]: Bart --> 35 ...
---   person[2]: Max --> 42 ...
---   person[3]: Homer --> 55 ...
---   person[4]: Yogi --> 65 ...
---   person[5]: Charlie --> 72 ...
--- ======================================== ...
--- Leave TestDictionnary03.main()           ...
```

Spatial Data and Dataset Transformation

(GeoPandas)

GeoPandas

GeoPandas

GeoPandas is an open source project to make working with geospatial data in Python easier.

Approach:

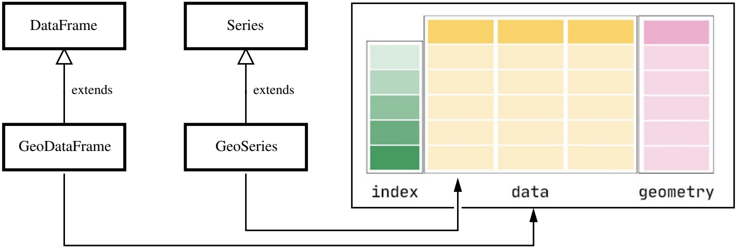
- Extend the datatypes used by Pandas to allow spatial operations on geometric types.
- Geometric operations are performed by shapely.
- Geopandas further depends on fiona for file access and matplotlib for plotting.

Installation

```
prompt >> pip3 install geopandas
```

Working with GeoPandas Dataframes

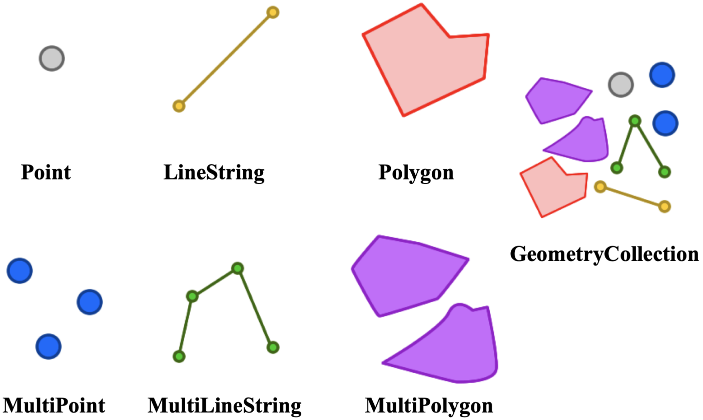
Core Modeling Concepts and Data Structure:



- GeoSeries handle geometries (points, polygons, etc).
- GeoDataFrames store geometry columns and perform spatial operations. They can be assembled from geopandas.GeoSeries.

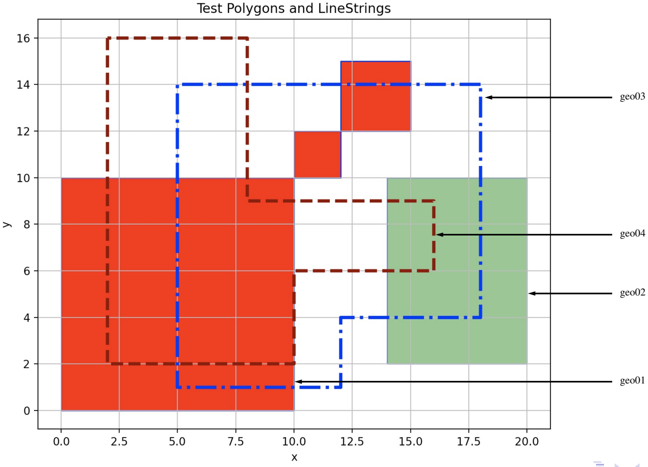
Working with GeoPandas Dataframes

Geometric Objects: points, multi-points, lines, multi-lines, polygons, multi-polygons.



Example 10: Manual Specification of Geometric Shapes

Example 10: Manual specification of polygon and linestring shapes ...



Example 10: Manual Specification of Geometric Shapes

Part I: Problem Setup

```
# ========================================================================
# TestGeoSeries01.py. Manual assembly of simple geometries.
#
# Written by: Mark Austin                                    February 2023
# ========================================================================

import geopandas
from geopandas import GeoSeries
from shapely.geometry import Polygon
from shapely.geometry import LineString

import matplotlib.pyplot as plt

# ==============================
# main method ...
# ==============================

def main():
    print("--- Enter TestGeoSeries01.main()             ... ");
    print("--- ======================================== ... ");

    print("--- Part 01: Create individual polygons ... ");

    polygon01 = Polygon([   (0,0),  (10,0), (10,10),  (0,10) ] )
    polygon02 = Polygon([ (10,10), (12,10), (12,12), (10,12) ] )
    polygon03 = Polygon([ (12,12), (15,12), (15,15), (12,15) ] )
```

Example 10: Manual Specification of Geometric Shapes

Part I: Problem Setup (Continued) ....

```
polygon04 = Polygon([ (14,2), (20,2), (20,10), (14,10) ] )

print("--- Part 02: Add polygons to GeoSeries ... ");

geo01 = GeoSeries( [ polygon01, polygon02, polygon03 ]);
geo02 = GeoSeries( [ polygon04 ]);

print("--- Part 03: Create simple linestring GeoSeries ... ");

line01 = LineString([ (18,14), (5,14), (5,1), (12,1), (12,4), (18,4), (18,14) ] )
geo03  = GeoSeries( [ line01 ]);
line02 = LineString([ (2,16), (2,2), (10,2), (10,6), (16,6), (16,9), (8,9), (8,16),
geo04  = GeoSeries( [ line02 ]);

print("--- Part 04: Print GeoSeries info and contents ... ");

print(geo01)
print(geo02)

print("--- Part 05: Area and boundary of geo01 ... ");

print(geo01.area)
print(geo01.boundary)

print("--- Part 06: Area and boundary of geo02 ... ");

print(geo02.area)
print(geo02.boundary)
```

Example 10: Manual Specification of Geometric Shapes

Part I: Problem Setup (Continued) ....

```

    print("--- Part 07: Spatial relationship of geo01 through geo04 ... ");

    print("--- Compute intersection of (lines) geo03 and geo04 ...")
    geo02a = geo03.intersects(geo04)
    print("---   geo03.intersects(geo04) --> {:s} ...".format( str( geo02a[0] ) ))
    geo02b = geo03.intersection(geo04)
    print("---   geo03.intersection(geo04) --> {:s} ...".format( str( geo02b[0] ) ))

    print("--- Compute intersection of (region) geo01 and (lines) geo03 and geo04 ...")
    geo02c = geo01.intersection(geo03)
    print("---   geo01.intersection(geo03) --> {:s} ...".format( str( geo02c[0] ) ))
    geo02d = geo01.intersection(geo04)
    print("---   geo01.intersection(geo04) --> {:s} ...".format( str( geo02d[0] ) ))

    print("--- Compute intersection of (region) geo02 and (lines) geo03 and geo04 ...")
    geo02e = geo02.intersection(geo03)
    print("---   geo02.intersection(geo03) --> {:s} ...".format( str( geo02e[0] ) ))
    geo02f = geo02.intersection(geo04)
    print("---   geo02.intersection(geo04) --> {:s} ...".format( str( geo02f[0] ) ))

    print("--- Part 08: Plot polygons ... ");

    ax = geo01.plot( color=’blue’, edgecolor=’black’)
    ax.set_aspect(’equal’)
    ax.set_title("Test Polygons and LineStrings")
```

Example 10: Manual Specification of Geometric Shapes

Part I: Problem Setup (Continued) ....

```

    # Plot polygons ...

    geo01.plot(ax=ax, edgecolor=’blue’, color=’red’,   alpha= 1.0 )
    geo02.plot(ax=ax, edgecolor=’blue’, color=’green’, alpha= 0.5 )

    # Plot linestring ...

    geo03.plot(ax=ax, color=’blue’,   alpha= 1.0, linewidth=3.0, linestyle=’dashdot’ )
    geo04.plot(ax=ax, color=’maroon’, alpha= 1.0, linewidth=3.0, linestyle=’dashed’ )

    plt.xlabel(’x’)
    plt.ylabel(’y’)
    plt.grid(True)
    plt.show()

    print("--- ======================================== ... ");
    print("--- Leave TestGeoSeries01.main()             ... ");

# ==================================================
# call the main method ...
# ==================================================

main()
```

Source Code: See: python-code.d/geopandas/

Example 10: Manual Specification of Geometric Shapes

Part II: Abbreviated Output:

```
--- Enter TestGeoSeries01.main()             ...
--- Part 01: Create individual polygons ...
--- Part 02: Add polygons to GeoSeries ...
--- Part 03: Create simple linestring GeoSeries ...

--- Part 04: Print GeoSeries info and contents ...

0    POLYGON ((0.00000 0.00000, 10.00000 0.00000, 1...
1    POLYGON ((10.00000 10.00000, 12.00000 10.00000...
2    POLYGON ((12.00000 12.00000, 15.00000 12.00000...
dtype: geometry
0    POLYGON ((14.00000 2.00000, 20.00000 2.00000, ...
dtype: geometry

--- Part 05: Area and boundary of geo01 ...

0    100.0
1      4.0
2      9.0
dtype: float64
0    LINESTRING (0.00000 0.00000, 10.00000 0.00000,...
1    LINESTRING (10.00000 10.00000, 12.00000 10.000...
2    LINESTRING (12.00000 12.00000, 15.00000 12.000...
dtype: geometry
```

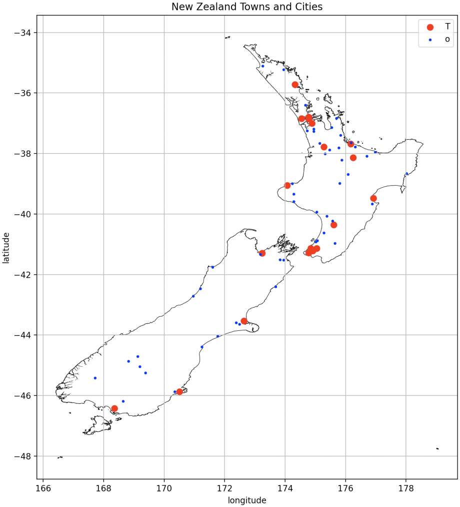
Example 10: Manual Specification of Geometric Shapes

Part II: Abbreviated Output:

```
--- Part 06: Area and boundary of geo02 ...

0    48.0
dtype: float64
0    LINESTRING (14.00000 2.00000, 20.00000 2.00000...
dtype: geometry

--- Part 07: Spatial relationship of geo01 through geo04 ...

--- Compute intersection of (lines) geo03 and geo04 ...

---   geo03.intersects(geo04) --> True ...
---   geo03.intersection(geo04) --> MULTIPOINT (5 2, 8 14) ...

--- Compute intersection of (region) geo01 and (lines) geo03 and geo04 ...

---   geo01.intersection(geo03) --> LINESTRING (5 10, 5 1, 10 1) ...
---   geo01.intersection(geo04) --> MULTILINESTRING ((10 2, 10 6), (2 10, 2 2, 10 2), (10 9, 8 9, 8 10))

--- Compute intersection of (region) geo02 and (lines) geo03 and geo04 ...

---   geo02.intersection(geo03) --> LINESTRING (14 4, 18 4, 18 10) ...
---   geo02.intersection(geo04) --> LINESTRING (14 6, 16 6, 16 9, 14 9) ...

--- Part 08: Plot polygons ...
--- Leave TestGeoSeries01.main()             ...
```

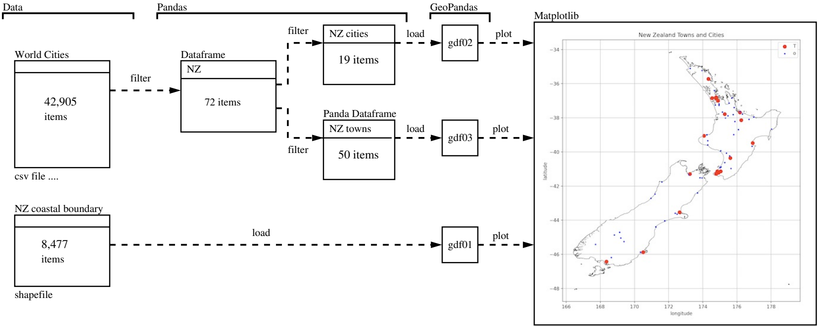
Example 11: Towns and Cities in New Zealand

Example 11: Towns and Cities in New Zealand.



Example 11: Towns and Cities in New Zealand

Part I: Data Processsing Pipeline: Use sequence of filters to specialize views of data ...



Data

Pandas

GeoPandas

Matplotlib

World Cities

42,905 items

csv file ....

filter

Dataframe

NZ

72 items

filter

NZ cities

19 items

load

gdf02

plot

Panda Dataframe

NZ towns

50 items

filter

load

gdf03

plot

NZ coastal boundary

8,477 items

shapefile

load

gdf01

plot

Example 11: Towns and Cities in New Zealand

Part II: Program Source Code:

```
# ========================================================================
# TestNewZealandDataModel.py. Assemble data model for towns and cities in
# New Zealand.
#
# Written by: Mark Austin                                    February 2023
# ========================================================================

from pandas import DataFrame
from pandas import Series
from pandas import read_csv

import numpy as np
import pandas as pd
import geopandas

import matplotlib.pyplot as plt

# ==============================
# main method ...
# ==============================

def main():
    print("--- Enter TestNewZealandDataModel.main()     ... ");
    print("--- ======================================== ... ");

    print("--- Part 01: Load world city dataset ... ");
```

Example 11: Towns and Cities in New Zealand

Part II: Program Source Code: (Continued) ...

```

    df = pd.read_csv("../data/cities/world-cities.csv")

    print("--- Part 02: Print dataframe info and contents ... ");

    print(df)
    print(df.info() )

    print("--- Part 03: Filter dataframe to keep only cities from New Zealand ... ")

    options = ['New Zealand']
    dfNZ       = df [ df['country'].isin(options) ].copy()

    print("--- Part 04: Filter data to find NZ cities and towns ... ")

    dfNZcities = dfNZ [ (dfNZ['population'] > 40000) ].sort_values( by=['population'] )

    dfNZtowns  = dfNZ [ (dfNZ['population'] > 1000) & (dfNZ['population'] < 40000) ]
    dfNZtowns  = dfNZtowns.sort_values( by=['population'] )

    print('--- New Zealand Cities:\n', dfNZcities )
    print('--- New Zealand Towns:\n', dfNZtowns )

    print("--- Part 05: Read NZ coastline shp file into geopandas ... ")

    nzboundarydata = geopandas.read_file("../data/geography/nz/Coastline02.shp")
    print(nzboundarydata)
```

Example 11: Towns and Cities in New Zealand

Part II: Program Source Code: (Continued) ...

```
    print("--- Part 06: Define geopandas dataframes ... ")

    gdf01 = geopandas.GeoDataFrame(nzboundarydata)
    gdf02 = geopandas.GeoDataFrame( dfNZcities,
                 geometry=geopandas.points_from_xy(dfNZcities.lng, dfNZcities.lat))
    gdf03 = geopandas.GeoDataFrame(  dfNZtowns,
                 geometry=geopandas.points_from_xy( dfNZtowns.lng, dfNZtowns.lat))

    print(gdf01.head())

    print("--- Part 07: Create boundary map for New Zealand ... ")

    # We can now plot our ``GeoDataFrame``.

    ax = gdf01.plot( color='white', edgecolor='black')
    ax.set_aspect('equal')
    ax.set_title("New Zealand Towns and Cities")

    gdf01.plot(ax=ax, color='white')

    gdf02.plot(ax=ax, color =  'red', markersize = 50, label= 'Cities')
    gdf03.plot(ax=ax, color = 'blue', markersize =  5, label= 'Towns' )

    plt.legend('Towns/Cities:')
    plt.xlabel('longitude')
    plt.ylabel('latitude')
```

Example 11: Towns and Cities in New Zealand

Part II: Program Source Code: (Continued) ...

```
    plt.grid(True)
    plt.show()

    print("--- ======================================== ... ");
    print("--- Leave TestNewZealandDataModel.main()      ... ");

# ==================================================
# call the main method ...
# ==================================================

main()
```

Source Code: See: python-code.d/geopandas/

Example 11: Towns and Cities in New Zealand

Part III: Abbreviated Output:

```
--- Enter TestNewZealandDataModel.main()     ...
--- ======================================== ...
--- Part 01: Load world city dataset ...
--- Part 02: Print dataframe info and contents ...
             city  city_ascii      lat  ... capital population         id
0           Tokyo       Tokyo  35.6839  ... primary 39105000.0 1392685764
1         Jakarta     Jakarta  -6.2146  ... primary 35362000.0 1360771077
...           ...         ...      ...  ...     ...        ...        ...
42903 Timmiarmiut Timmiarmiut  62.5333  ...     NaN       10.0 1304206491
42904     Nordvik     Nordvik  74.0165  ...     NaN        0.0 1643587468
[42905 rows x 11 columns]

<class ’pandas.core.frame.DataFrame’>
RangeIndex: 42905 entries, 0 to 42904
Data columns (total 11 columns):
 #   Column      Dtype             #   Column      Dtype
---  ------      -----            ---  ------      -----
 0   city        object            6   iso3        object
 1   city_ascii  object            7   admin_name  object
 2   lat         float64           8   capital     object
 3   lng         float64           9   population  float64
 4   country     object           10   id          int64
 5   iso2        object
dtypes: float64(3), int64(1), object(7)
memory usage: 3.6+ MB
```

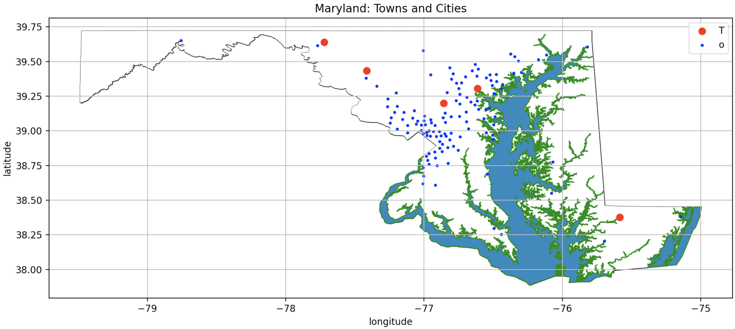
Example 11: Towns and Cities in New Zealand

Part III: Abbreviated Output (Continued) ...

```
--- Part 03: Filter dataframe to keep only cities from New Zealand ...
--- Part 04: Filter data to find NZ cities and towns ...

--- New Zealand Cities:
                    city        city_ascii  ...  population          id
14169        Upper Hutt        Upper Hutt  ...     41000.0  1554000042
6159       Invercargill      Invercargill  ...     47625.0  1554148942
.....
741          Wellington        Wellington  ...    418500.0  1554772152
516            Auckland          Auckland  ...   1346091.0  1554435911
[19 rows x 11 columns]

--- New Zealand Towns:
                   city       city_ascii  ...  population          id
42142         Kaikoura         Kaikoura  ...      2210.0  1554578431
.....
14309        Whanganui        Whanganui  ...     39400.0  1554827998
[50 rows x 11 columns]

--- Part 05: Read NZ coastline shp file into geopandas ...
0     POLYGON ((174.00369 -40.66489, 174.00372 -40.6...
.....
8476  POLYGON ((173.01384 -34.39348, 173.01395 -34.3...
[8477 rows x 1 columns]
--- Part 07: Create boundary map for New Zealand ...
--- ======================================== ...
--- Leave TestNewZealandDataModel.main()     ...
```

Example 12: Towns and Cities in Maryland

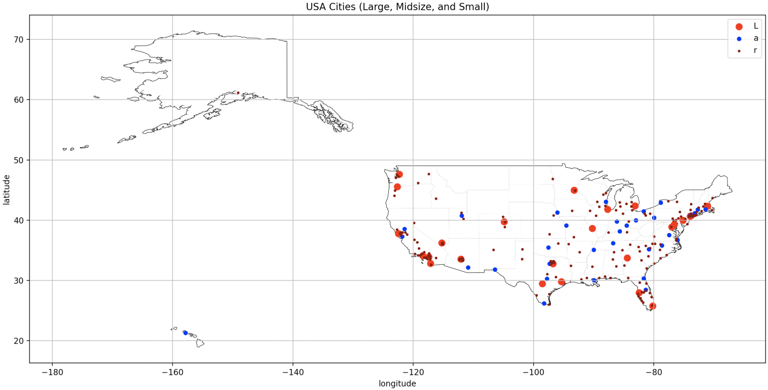
Example 12: Towns and Cities in Maryland.



Cities: Columbia (pop. 103991), Salisbury (pop. 106447), Frederick (pop. 156787), Hagerstown (pop. 184755), Baltimore (pop. 2106068).

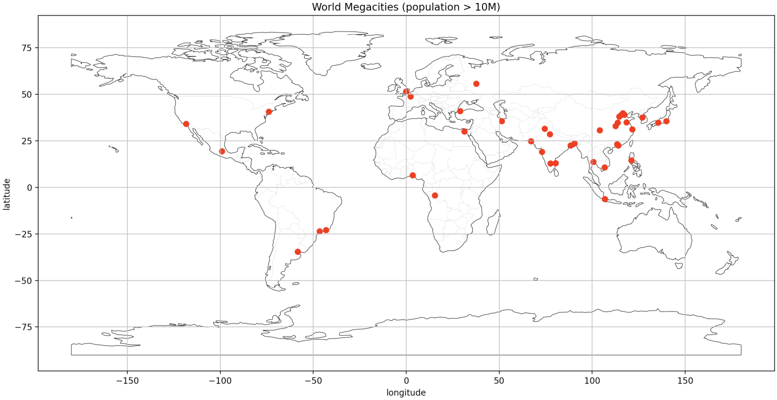
Example 13: Large, Midsize, and Small US Cities

Example 13: Large, Midsize, and Small US Cities



Cities: 26 large (pop. > 2M), 34 midsize (800k < pop. < 2M), 172 small (200k < pop. < 800k).

Example 14: The World’s Megacities



Example 14: The World's Megacities

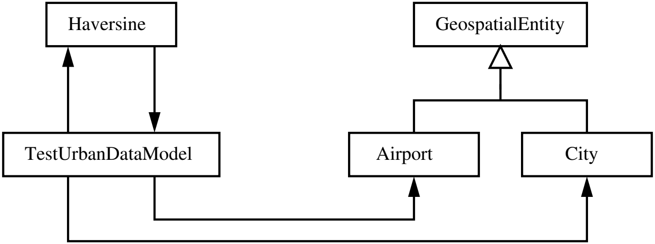
```
--- Part 02: Filter to keep only large cities (pop. > 10M) ...

                city        city_ascii  ...  population          id
0              Tokyo             Tokyo  ...  39105000.0  1392685764
1            Jakarta           Jakarta  ...  35362000.0  1360771077
2              Delhi             Delhi  ...  31870000.0  1356872604
3             Manila            Manila  ...  23971000.0  1608618140
4          São Paulo         Sao Paulo  ...  22495000.0  1076532519
5              Seoul             Seoul  ...  22394000.0  1410836482
6             Mumbai            Mumbai  ...  22186000.0  1356226629
7           Shanghai          Shanghai  ...  22118000.0  1156073548
8        Mexico City       Mexico City  ...  21505000.0  1484247881
9          Guangzhou         Guangzhou  ...  21489000.0  1156237133
10             Cairo             Cairo  ...  19787000.0  1818253931
11           Beijing           Beijing  ...  19437000.0  1156228865
12          New York          New York  ...  18713220.0  1840034016
13           Kolkāta           Kolkata  ...  18698000.0  1356060520
14            Moscow            Moscow  ...  17693000.0  1643318494
15           Bangkok           Bangkok  ...  17573000.0  1764068610

... details removed ...

33            London            London  ...  11120000.0  1826645935
34             Paris             Paris  ...  11027000.0  1250015082
35           Tianjin           Tianjin  ...  10932000.0  1156174046
36             Linyi             Linyi  ...  10820000.0  1156086320
37      Shijiazhuang      Shijiazhuang  ...  10784600.0  1156217541
38         Zhengzhou         Zhengzhou  ...  10136000.0  1156183137
39           Nanyang           Nanyang  ...  10013600.0  1156192287
```

Case Study

(GeoModeling Spatial Entities)

Case Study: GeoModeling Spatial Entities

Geospatial Data Model: Create city and airport models. Use Haversine formula to compute distances between entities.



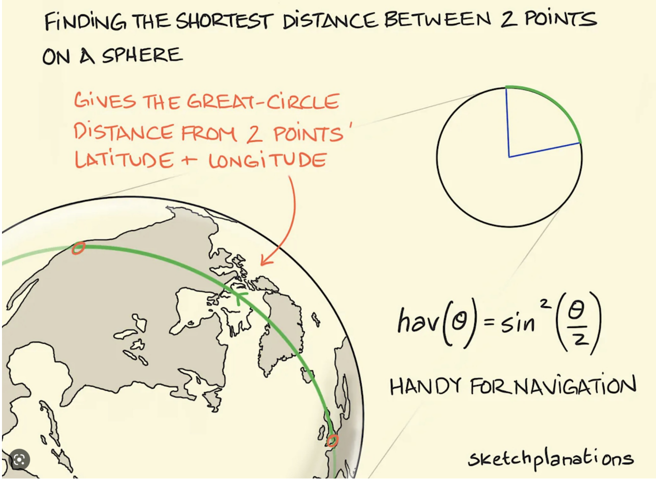
Geospatial Attributes: latitude, longitude, elevation.

City Attributes: name, population, state, country.

Airport Attributes: name, airport code.

Case Study: GeoModeling Spatial Entities

Haversine Formula


FINDING THE SHORTEST DISTANCE BETWEEN 2 POINTS ON A SPHERE
GIVES THE GREAT-CIRCLE DISTANCE FROM 2 POINTS' LATITUDE + LONGITUDE
$hav(\theta) = \sin^2\left(\frac{\theta}{2}\right)$
HANDY FOR NAVIGATION
sketchplanations

Case Study: GeoModeling Spatial Entities

Haversine Formula: Source code ...

```
# =========================================================================
# Haversine.py. Small class that provides approximate distance (km) between
# two points using the Haversine formula.
#
# Call in a static context:
#
# Haversine.distance(47.6788206, -122.3271205,
#                    47.6788206, -122.5271205) --> 14.973190481586224 [km]
#
# earthRadius = 6372.8;    # Earth radius in KM
# earthRadius = 3959.87433 # Earth radius in miles.
#
# Written by: Jason Winn (http://jasonwinn.org)
# Modified by: Mark Austin                                    February 2023
# =========================================================================

from math import radians, cos, sin, asin, sqrt

class Haversine:

    # =====================================
    # Compute haversine distance ...
    # =====================================

    @staticmethod
    def distance(lat1, lon1, lat2, lon2):
```

Case Study: GeoModeling Spatial Entities

Haversine Formula: Source code ...

```
        earthRadius = 3959.87433 # Earth radius in miles.
        dLat = radians(lat2 - lat1)
        dLon = radians(lon2 - lon1)
        lat1 = radians(lat1)
        lat2 = radians(lat2)

        a = sin(dLat/2)**2 + cos(lat1)*cos(lat2)*sin(dLon/2)**2
        c = 2*asin(sqrt(a))

        return earthRadius * c
```

Source Code: See: python-code.d/geospatial/

Case Study: GeoModeling Spatial Entities

Compute Distance between Washington DC and NYC

```
# ==========================================================
# TestHaversine.py: Small test program for haversine formula.
# ==========================================================

from Haversine import Haversine
from City import City
from Airport import Airport

# main method ...

def main():
    print("--- Enter TestHaversine.main()      ... ");
    print("--- =============================== ... ");

    print("--- Part 1: Create sample cities and airports ... ");

    city01 = City( "Washington DC", 38.907192, -77.036871, 410.0,  5 )
    city02 = City(     "Baltimore", 39.290385, -76.612189, 480.0, 10 )
    city03 = City(      "New York", 40.712784, -74.005941, 265.0, 10 )

    airport01 = Airport( "Baltimore-Washington", "BWI", 39.177404, -76.668392, 148.0 );
    airport02 = Airport( "Washington Dulles",    "IAD", 38.952934, -77.447741, 313.0 );

    print("--- Part 2: Print details of cities and airports ... ");

    print(city01);    print(city02); print(city03)
```

Case Study: GeoModeling Spatial Entities

Compute Distance between Washington DC and NYC

```
    print(airport01); print(airport02)

    print("--- Part 3: Compute distances between locations ... ");

    # Compute distance between Washington DC and Baltimore ...

    lat1 = city01.getLatitude(); lon1 = city01.getLongitude()
    lat2 = city02.getLatitude(); lon2 = city02.getLongitude()
    d1 = Haversine.distance(lat1, lon1, lat2, lon2)

    print("--- Distance: Washington DC to Baltimore --> {:f} miles ..".format(d1))

    # Compute distance between Washington DC and New York ...

    lat1 = city01.getLatitude(); lon1 = city01.getLongitude()
    lat2 = city03.getLatitude(); lon2 = city03.getLongitude()

    d1 = Haversine.distance(lat1, lon1, lat2, lon2)

    print("--- Distance: Washington DC to New York --> {:f} miles ..".format(d1))

    # Compute distance between IAD and BWI ...

    lat01 = airport01.getLatitude(); lon01 = airport01.getLongitude()
    lat02 = airport02.getLatitude(); lon02 = airport02.getLongitude()

    d1 = Haversine.distance( lat01, lon01, lat02, lon02)
```

Case Study: GeoModeling Spatial Entities

Compute Distance between Washington DC and NYC

```

    code01 = airport01.getAirportCode()
    code02 = airport02.getAirportCode()
    print("--- Distance: {:s} to {:s} --> {:f} miles ..".format( code01, code02, d1))

    print("--- =============================== ... ");
    print("--- Leave TestHaversine.main()      ... ");

# call the main method ...

main()
```

Source Code: See: python-code.d/geospatial/

Case Study: GeoModeling Spatial Entities

Abbreviated Output:

```
--- Enter TestHaversine.main()      ...
--- =============================== ...
--- Part 1: Create sample cities and airports ...
--- Part 2: Print details of cities and airports ...

--- City: Washington DC ...
--- -------------------------------------------------
---   Latitude   =    38.907192 ...
---   Longitude  =   -77.036871 ...
---   Elevation (highest) = 410.00 ft ...
---   Population =   5.00 ...
--- -------------------------------------------------

--- City: Baltimore ...
--- -------------------------------------------------
---   Latitude   =    39.290385 ...
---   Longitude  =   -76.612189 ...
---   Elevation (highest) = 480.00 ft ...
---   Population =  10.00 ...
--- -------------------------------------------------

--- City: New York ...
--- -------------------------------------------------
---   Latitude   =    40.712784 ...
---   Longitude  =   -74.005941 ...
---   Elevation (highest) = 265.00 ft ...
---   Population =  10.00 ...
--- -------------------------------------------------
```

Case Study: GeoModeling Spatial Entities

Abbreviated Output: (Continued) ...

```
--- Airport: Baltimore-Washington (BWI) ...
--- -------------------------------------------------
---   Latitude   =    39.177404 ...
---   Longitude  =   -76.668392 ...
---   Elevation (highest) = 148.00 ft ...
--- -------------------------------------------------

--- Airport: Washington Dulles (IAD) ...
--- -------------------------------------------------
---   Latitude   =    38.952934 ...
---   Longitude  =   -77.447741 ...
---   Elevation (highest) = 313.00 ft ...
--- -------------------------------------------------

--- Part 3: Compute distances between locations ...

--- Distance: Washington DC to Baltimore --> 34.931571 miles ..
--- Distance: Washington DC to New York --> 203.608912 miles ..
--- Distance: BWI to IAD --> 44.605415 miles ..

--- =============================== ...
--- Leave TestHaversine.main()      ...
```

References

- ....
- ....